

ENVIRONMENTAL STATUS OF THE COASTAL MARINE ENVIRONMENT OF INDIA

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The urban and industrial pockets along the Indian coast, release their wastewater often untreated, to nearby coastal waters and estuaries. Several nearshore areas and estuaries mainly along the west coast, have been studied over the past decade to evaluate the impact of wastewater release on the marine ecology. These studies are reviewed in this article to have an integrated profile of the environmental status of the coastal waters of India. It is concluded that the coastal waters are unpolluted except for some localised and severely to moderately polluted 'hot spots' adjacent to urban and industrial areas. However, many of the estuaries are showing signs of environmental degradation and some of them are severely polluted.

INTRODUCTION

India has a coastline of 7500 km. with an exclusive economic zone of 2.015×10^6 km² which is 61% of the land area. The country has 14 major, 44 medium and 162 minor rivers with a total catchment area of 3.12×10^6 km², discharging 1645 km³ of freshwater every year to the seas around the country. The important major rivers are Ganga, Mahanadi, Godavari, Krishna and Kaveri on the east coast and Narmada and Tapi on the west coast. These seven rivers drain a catchment area of 1.83×10^6 km² and discharge 812 km³ of freshwater transporting 1194×10^6 t of silt to the marine waters every year.

There are more than 30 medium and large urban pockets along the coast where some kind of organised water supply and sewerage systems are existing. With increasing urbanization and growth of industries along the coast, the nearshore water bodies including estuaries, have been looked upon than ever before as convenient recipients of a variety of pollutants.

Until recently, the wastes were being released to the coastal marine environment without proper scientific studies to ascertain the waste assimilation capacities of the receiving waters. However, recent public awareness of aquatic pollution and several positive steps taken by the government have resulted in surveying, although to a limited extent, several coastal areas and estuaries.

COASTAL WATERS

TRIVANDRUM

A titanium dioxide factory discharged the wastewater (4000 m³/day) containing sulphuric acid, ferrous salts and titanium dioxide into the coastal waters of Trivandrum. The effluent spread along the coast, northward or southward, depending on the direction and force of the littoral drift. The oxidation of ferrous to ferric iron, apart from affecting the oxygen levels in water imparted a reddish brown colour to the seawater. A decrease in intertidal and benthic fauna was observed although gross ecological variations had not occurred (Menon *et al.*, 1979).

MANGALORE

The nearshore waters of Mangalore received wastewater from a fertilizer factory and an iron ore company. Relatively high water and sediment nutrient contents in the receiving water have been attributed to the wastewater inputs. Although there were no major alterations to the environment, the predominance and persistence of certain species of phytoplankton and a decline in zooplankton biomass and density was considered to be due to the deterioration of water quality (Devassy *et al.*, 1987).

KARWAR

Binge Bay (Karwar) an important fishing centre, received mercury containing discharges of a factory manufacturing caustic soda among other products. Though no significant increase in mercury was noticed in organisms, sediments and seawater of the bay and regions around, very high concentrations were observed in water and sediments of a small tidal channel draining into Binge Bay (Kureishy *et al.*, 1987).

GOA

The coastal waters of Goa have been studied in fair details with respect to nutrients, trace metals and petroleum residues (Singbal 1981; Zingde *et al.*, 1976; Fondekar, 1980). The waters were generally unpolluted except for Velcaon Bay which received wastewater (15000 m³/day) from a fertilizer factory with arsenic, ammonia and urea as major contaminants. The levels of PO₄³⁻-P, NO₃⁻-N, NO₂⁻-N and NH₄⁺-N were abnormally high in the bay (Zingde *et al.*, 1979a). The trace metals in water sediment and biota however, revealed normal background levels (Singbal, 1981; Zingde *et al.*, 1976).

Environment of
II-1 Marine L BOMBAY →

The coastal marine environment of Bombay has been investigated in great details to delineate the impact of wastes on the water quality and ecology. The domestic wastewater (1.8 x 10⁶ m³/day) generated in the city is released untreated or partially treated, to nearby creeks, bays or directly to the coastal waters through point discharges. It has been estimated

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that around 450 t of BOD, 63 t of N, 11 t of P, 0.18 t of Cu, 0.36 t of Zn, and 0.09 t of Pb entered the marine waters every day through domestic wastewater alone (Zingde, 1988a). Although the coastal waters also received large quantities of industrial wastewater, the quantitative information was not available (Zingde, 1985a). A rough estimate of the industrial wastewater generated in Bombay and the regions around (New Bombay and Ulhas) was put at $5 \times 10^5 \text{ m}^3/\text{day}$, a major fraction of which being released in Thana Creek/Bombay Harbour and Ulhas River/Bassein creek.

The wastewater entering the marine environment has severely deteriorated the water quality in some regions. The salinity of some creeks and bays varied considerably even in dry season because of the wastewater discharges. The incomplete mixing of low saline contaminated inshore water and high saline seawater intruding during high tide resulted in appreciable vertical salinity gradient. Thus for example, in Mahim Bay this gradient frequently exceeded 7‰, specially during the flood tide and although there was no freshwater discharge through Mahim River, the salinities as low as 15‰ were common during ebb tide in summer (Zingde and Desai, 1980a).

Beyond 10 m depth contour (offshore) where the impact of organic waste was low, dissolved oxygen (DO) of 6 mg/l during August increased to attain maximum (8-9 mg/l) during January- February followed by a decrease till May. Here, the vertical distribution of DO was fairly uniform with only a marginal decrease with depth. Substantial reduction in DO on the contrary, was a common feature in regions receiving organic waste (Zingde, 1985a). Thus, in Mahim Bay (Zingde, 1985a) and Versova Creek (Zingde *et al.*, 1979a) DO levels were tide dependent with values often falling to 0 mg/l at low tides. The BOD here exceeded 20 mg/l during low tide while the offshore waters had BOD below 2 mg/l. A marked decrease in DO along the length of Thana Creek-Bombay Harbour during postmonsoon occurred as the freshwater entering the head of Thana Creek through the arm of Ulhas River became negligible after September (Zingde *et al.*, 1979b). The surface water in polluted creeks often had low DO as compared to the more saline bottom water and it was not surprising to observe bottom DO as high as 4 mg/l when the DO at the surface was below 1 mg/l (Zingde *et al.*, 1980a).

From the pattern of DO and BOD distribution it appeared that the organic load entering every day (450 t of BOD) was being effectively dispersed by the tidal currents and assimilated in the nearshore waters itself and their transport offshore was not detectable.

Due to high oxygen demand, the oxidation of organic matter was only partial in the bays and creeks and complete mineralisation occurred only when the waste reached the open coast accounting for high NO_3^- -N and PO_4^{3-} -P in nearshore waters (Zingde, 1985a). The polluted creeks on the contrary had high concentrations of NH_4^+ -N and NO_2^- -N was often low due to nonavailability of DO for the oxidation of ammonia released through wastewater. The conditions often went to reducing and as high as 37-126 $\mu\text{g-at/l}$ of H_2S -S has been reported in Mahim Creek (Sabnis, 1984).

The concentrations of dissolved trace metals in the offshore were low and close to the natural background (Zingde *et al.*, 1989; Sahu and Khopkar, 1987). The levels of dissolved Ni, Cu, Zn and Hg were however, somewhat higher in Thana Creek (Zingde *et al.*, 1989; Zingde and Desai, 1981a). The water in Thana Creek-Bombay Harbour has been reported to have about 77 Kg of Hg in excess of the expected background (Zingde and Desai, 1981a). The dissolved trace metals in water column of Harbour though varied appreciably, there were no major systematic fluctuations and there was no evidence of any increase in the concentration over the years (Zingde *et al.*, 1989; Patel *et al.*, 1985). In Mahim Creek the concentrations of dissolved trace metals were decided not only by the solubility of hydroxides and formation of metal complexes, but also by the solubility of sulphides of respective metals under prevailing anoxic conditions. It was therefore, not surprising to observe low levels (2-4 $\mu\text{g/l}$) of Cu in Mahim Creek though higher concentrations were observed in nearby coastal water (Sabnis, 1984; Zingde, 1985a). The decrease of Zn was 103 $\mu\text{g/l}$ in Mahim Bay to as low as 6 $\mu\text{g/l}$ in the interior of Mahim Creek while levels of Mn increased from 10 $\mu\text{g/l}$ to 150 $\mu\text{g/l}$ respectively.

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Trace metals in the suspended matter revealed only marginal enrichment of Ni, Cu and Zn in Thana Creek region (Zingde *et al.*, 1989) and high enrichment in Mahim Creek (Sabnis, 1984) while the levels in the suspended load of coastal waters were more or less comparable to those observed for other nearshore environments. The variation of element concentration with salinity revealed considerable scatter and no systematic trend was observed (Zingde *et al.*, 1989).

Trace metals in the sediment cores from coastal waters of Bombay did not reveal any significant enrichment in surface layers (Srinivasan and Mahajan, 1987). The sediments from Mahim Creek however, showed considerable enrichment. The surface concentration of Cu was as high as 800 ppm and that of Zn exceeded 2500 ppm as against 105 ppm and 138 ppm respectively observed in the offshore (Sabnis, 1984). Likewise organic C was as high as 15% and phosphorus exceeded 2000 ppm indicating the severity of sediment contamination in Mahim Creek region. It has been estimated that the top 20 cm sediment in Mahim Creek contained 4.3 t of Ni, 37 t of Cu, 106 t of Zn and 4.6 t of Pb in excess over the expected background (Sabnis, 1984). In Thana Creek-Bombay Harbour the total Hg concentration in the surface sediments varied from 0.17 to 8.21 ppm with definite enrichment in the creek suggesting mercury inputs in the upper reaches. The mercury enriched layer in the sediment cores was about 10-25 cm in the creek and 0-8 cm in the harbour area. An excess of 14 t of Hg over the natural background has been estimated to be trapped in these sediments (Zingde and Desai, 1981a). Cd concentrations in the suspended particles and the sediments were in the range of 0.5 to 6.1 ppm and was largely controlled by the physico-chemical determinants of the environment namely pH, organic matter, cation exchange capacity and industrial inputs (Bhosle and Sahu, 1987). The variation of Pb, Zn and Cd with depth in sediment cores was irregular, perhaps because of the reworking of sediments (Pillai *et al.*, 1987).

The wastewater from Bhabha Atomic Research Centre was the major source of low level radioactive waste to the bay. The main radio-nuclides present in the waste were ^{137}Cs .

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144 Ce, 106 Ru, 95 Zr/Nb, 90 Sr, and its daughter products and traces of 239 Pu. The levels of various radionuclides in water, sediment and benthic organisms have been found to be within permissible limits (Patel and Patel, 1982).

Macrobenthic fauna of Thana Creek-Bombay Harbour indicated three different zones of production. The creek head an area of about 4 km² had a rich macrobenthic biomass. A zone of moderate benthic organisms was observed in the harbour region. The lowest production confined to the middle section of Thana Creek was considered to be due to pollution loads in the vicinity (Govindan *et al.*, 1976). The mangroves of Mahim Bay were completely devoid of marine animals. A definite depletion in rock oyster and clam fishery inside the bay was quite evident. The creek region which was a source of rich oyster fishery about 40 years back has been completely devoid of living oysters (Govindan and Desai, 1980-81). Studies on distribution of copepods revealed that polluted regions of Mahim and Thana Creek had the dominance of *Paracalanus*, *Oithona* and *Acartia* while the generic diversity of copepods was greater in unpolluted areas (Gajbhiye *et al.*, 1981a). Likewise, greater diversity of fish larvae at Versova and harbour as compared to Mahim and Thana indicated the deteriorating environmental conditions at Mahim and Thana Creek (Gajbhiye *et al.*, 1982). Although chlorophyll was high in inshore waters, the polluted regions were marked by high phycophytin suggesting high rate of mortality of phytoplankton. Also, species diversity was high at unpolluted regions compared to polluted regions (Nair *et al.*, 1981a; Gajbhiye *et al.*, 1984).

The levels of trace metals in various species of fishes were within the permissible limits for human consumption except in isolated cases. Mercury in crab muscle however increased from 0.3-1.3 ppm offshore to 7.3 ppm in Thana Creek on wet weight basis (UNEP, 1985).

Studies undertaken in the coastal waters of Thal, a place about 30 km south of Bombay, however, did not reveal any influence of pollution from Bombay city on the water quality, sediment contamination as well as biological characteristics (Zingde *et al.*, 1987a; Varshney *et al.*, 1983; Gajbhiye *et al.*, 1983). These studies were undertaken prior to the commissioning of giant fertilizer complex at Thal. Information on present status of the environment is however not available.]

TARAPORE

The effects of low-level liquid radioactive waste from Tarapur Atomic Station on the radioactivity of seawater, marine organisms have been investigated (Bhat *et al.*, 1981). The highest values of 131 I and marine sediments, seaweeds and 137 Cs observed at the outfall were only 4 and 6% of the maximum permissible concentration and were close to the background beyond 2 km away from the outfall. Instantaneous suspended silt absorption upto 5% for 137 Cs, 3% for 131 I and 99.5% for 60Co was found. Levels of 137 Cs, and 60 Co in sediments beyond 2 km from the outfall were below detection limits revealing that the radioactivity from the atomic power station was confined within 2 km from the point of entry in the coastal

waters. The radionuclide content of prawns, crabs, oysters, clams, lobsters, onchidium and nerita species from nearshore waters revealed annual average ^{131}I activity of less than 0.5% of the derived permissible limit. In case of radiocaesium, ^{60}Co and ^{90}Sr , the average activity was less than 0.1% of the derived limit. Prawns, Bombayduck and mackerel netted offshore did not show any ^{131}I or ^{60}Co activity, whereas their ^{137}Cs levels ranged from 0.5 to 1.5 Bq/Kg and their ^{90}Sr levels ranged from 0.1 to 0.4 Bq/Kg. These levels were mainly due to the pick up of wepon fall out activity. ^{65}Zn Could be detected only in oysters growing within 1 km of the outfall with the range of activity being 56 to 140 m Bq/Kg. Seafood species such as nerita obtained within 1 km of the outfall occasionally contained ^{63}Ni which ranged from below detection level to 1.3 Bq/Kg.

PORBANDAR

The wastewater from a soda ash industry containing abnormally high levels of inorganic suspended load and ammonia was released through a point discharge in highly productive coastal waters of Porbandar. The effluent because of its higher specific gravity as compared to sweater, preferentially remained in the bottom layer and could be traced upto a distance of 4 km from the wastewater release point. The surface layer in this region had normal levels of ammonia, pH and suspended solids while bottom water had characteristically higher concentration of ammonia and suspended solids and high pH. The biological characteristics of the area however did not reveal any abnormal impact of wastewater release (NIO, 1982a; Jiyalal Ram *et al.*, 1988).

GULF OF KUTCH

Gulf of Kutch is highly productive and has high fishery potential. The area is being considered for tidal power generation by constructing the main barrier of about 3.25 km length across Hansthal Creek which would accommodate the power house, sluices and navigation locks. Besides, three subsidiary barriers of about 500 m, 300 m and 250 m length would be constructed across Phang, Sara and Sanu-Creeks respectively (Gupta *et al.*, 1988). The construction of the tidal power project would not raise the maximum high water level. Therefore, there would be no extra submergence. Although migration of fishes to the inner gulf should not be affected as large passage would be available for them through sluitices, the decrease in current velocity and increased stagnation inside the basin may increase the rate of growth of algae. Also, the possible increase in the residence time in the basin due to the increase in low water volume would increase the probability of built up of pollutants if any wastewater is released in the basin (Zingde *et al.*, 1988b).

An industry manufacturing industrial organic and inorganic chemicals released 18,000 m³/day of wastewater containing very high suspended load, above the high water line at Mithapur. A large portion of the suspended solids settled on the intertidal area and piled up along the beach. The liquid flowing into the gulf formed a narrow band along the shoreline (NIO, 1982b) and did not seem to affect the ecosystem (Gajbhiye *et al.*, 1988).

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KALPAKAM

The nuclear power reactors at Kalpakam use large quantities of seawater as a secondary coolant which after circulation through the condensers is released on the shore adjacent to the site. After the reactor had gone operational in July 1983 mean surface temperature of seawater in the vicinity has increased by 1°C. The seston content had shown a significant increase both during southwest and northeast monsoon periods decreasing the transparency of water. While gross productivity was not substantially different as compared to preoperational phase, net productivity decreased after the operations started (Nair, 1985).

VISAKHAPATNAM

Several major industries (manufacturing petroleum products, fertilizers, polymers, zinc, etc.) around Visakhapatnam Harbour, released their wastewater into the harbour through storm drainages. Appreciable quantities of domestic sewage also found its way into the harbour adding to the bulk of organic pollution in this area (Ganapati and Raman, 1979; Raman & Ganpati 1986, Subba Rao and Venkateshwar Rao, 1980). The harbour water was therefore characterised by abnormally high concentrations of nutrients, poor transparency, fluctuating salinity, high BOD and highly varying dissolved oxygen. The dominance of tubified populations indicated high degree of organic pollution in the harbour. High concentrations of nutrients and stagnation of the water due to inadequate tidal flushing resulted in periodic outbursts of phytoplankton blooms dominated by a single species of centric diatom *Skeletonema costatum* (Subba Rao and Venkateshwar Rao, 1980). The hydrographic structure of the nearshore waters suggested that the impact on the environment would be negligible if non-buoyant waste material was released in the offshore region through a submarine outfall (Prabhakara Rao and Ramesh Babu, 1986).

Apart from above discussed cases, studies related to nutrients, trace metals, petroleum residues, pesticides, primary productivity, zooplankton and benthos are reported for many other localities along the Indian coasts which generally indicate natural background levels.

Deposition of tar-like residues on the beaches however is more or less a chronic problem (UNEP, 1985; Kadam, 1988). This is a seasonal phenomenon depending on the pattern of coastal circulation largely regulated by the monsoons. Records from the west coast of India during 1975-76 indicated a range of 22 to 448 g/m² with the highest of 1386 g/m² observed on one occasion (UNEP, 1985). The total deposits on the beaches along the west coast has been estimated at 700-1000 t/yr. However, from 1977 to 1986 there has been a progressive decline in the occurrence of tar on the beaches (Sen Gupta *et al.*, 1988). Some of the beaches have also become vulnerable to human pathogens (NIO, 1974; Raveendran *et al.*, 1978; Unnithan *et al.*, 1985).

The mangroves along the Indian coast which apart from protecting the coastal and landward areas from erosion and cyclonic destruction to some extent, are important for

captive and culture fisheries, recreation and wildlife. These mangrove areas have suffered from indiscriminate reclamation, deforestation and pollution. The Gangetic Sunderbans, Cochin backwaters, Bombay region and Gulf of Kutch are examples of over exploitation, reclamation and pollution (UNEP, 1985; Untawale, 1987).

Coral reefs around India have also been affected due to several reasons. Dead as well as living coral beds have been exploited for the carbide industry and for white cement. Development of Tuticorin harbour and associated industrial activities as well as oil pollution has resulted in large scale destruction of coral reefs around Tuticorin. Impact of oil pollution on the corals of Minicoy and Kavaratti atolls and Great Nicobar island has been reported (UNEP, 1985).

ESTUARIES

COCHIN BACKWATERS (KERALA)

Considerable work has been done on the hydrography and the productivity of the Cochin backwaters (Unnithan *et al.*, 1985; Lakshmanan *et al.*, 1982 & 1987; Rama Raju *et al.*, 1979; Vijayan *et al.*, 1976). Extensive changes in hydrography have been reported due to the interbasin transfer of water from Periyar River to Muvattupuzha River to facilitate a hydroelectric project, construction of salt water barrier (Thanneermukham bund) on the southern part of the estuary and extensive dredging. In addition, the backwater system receives municipal sewage as well as wastewater from various industrial establishments.

The high monsoonal DO associated with the oxygenated rainwater gradually decreased as the season advanced to premonsoon. DO content of areas receiving organic waste fluctuated widely and level as low as 0.05 ml/l were observed in polluted localities (Vijayan *et al.*, 1976). Evidently BOD fluctuated spatially as well as temporally and values exceeding 100 mg/l were encountered in the polluted localities (Vijayan *et al.*, 1976). Although sulphide was absent in the unpolluted regions, levels of the order of 4 mg/l were observed in bottom waters of sewage influenced areas. Other reports however suggested no serious depletion of DO within the backwaters (Sarala Devi, 1979). NO_3^- -N and PO_4^{3-} -P revealed pronounced seasonal variations and distribution patterns. The barmouth region perhaps acted as a barrier between the northern and southern part of backwaters resulting in poor mixing between north and south parts of the estuary. Thus NO_3^- -N levels were below 2 ug-at/l in the southern estuary while northern estuary had NO_3^- -N below 5 ug-at/l. Likewise, the southern part exhibited NO_3^- -N concentration of 0-3 ug-at/l while in the northern portions the values ranged between 3-12 ug-at/l. Similar trend was observed for PO_4^{3-} -P. High nutrient levels have been identified in the waste disposed in the region from sewage works, fisheries industry, coconut husk-retting grounds and partly in the wastewater from the fertilizer factory. The high total P content of the sediments (0.9-2.4 mg/g) was due to the influence of domestic waste and on the basis of N/P ratio, it was concluded that the major portion of P in the sediments was of abiogenic origin (Sankaranarayanan *et al.*, 1979). Levels of Cu, Mn, Co, Ni and Zn in the sediments of northern arm have been reported. The main waste receiving sites revealed

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significant enrichment of Cu during monsoon and Zn during premonsoon (Venugopal *et al.*, 1982).

The localities affected by wastewater, indicated decrease in number of benthic organisms (Unnithan *et al.*, 1975). The mean value of polychaetes was found to be much less in the healthy zones as compared to marginal and polluted zones. Crustaceans and molluscs were few or absent in the marginal and polluted zones as compared to healthy areas. *Paraheteromastus tenuis* a capitellid polychaete totally dominated the benthic community of the retting grounds while spionid worm dominated the areas receiving municipal waste discharge (Remani *et al.*, 1983). Faecal pollution in some regions had crossed standards specified for shellfish culture or recreational activities (Pradeep and Lakshmanaperumal Swamy, 1986).

ASHTAMUDI ESTUARY (KERALA)

Ashtamudi estuary which is the second largest estuarine systems in Kerala received wastewater from a paper mill located on Kallada River, influencing the DO regime of the inner estuary. There were rapid and wide fluctuations in DO with total depletion resulting in the occurrence of brief anoxic periods ranging from a fortnight to a month throughout the inner estuary (Nair *et al.*, 1983a). The estuary segment receiving the wastewater revealed highest concentrations of total P and organic C in sediments (Nair *et al.*, 1983b; Nair *et al.*, 1984a). The levels of trace metals in sediments were also considered to be relatively high (Nair *et al.*, 1987). The fauna was extremely poor in the polluted segment of the estuary with low species diversity (Nair *et al.*, 1984b).

KALI RIVER ESTUARY (KARNATAKA)

Kali River estuary whose terrigenous transport enhances the nutrient budget of the coastal waters of Karwar supports rich biological production and serves as an ideal nursery ground for the young ones of fin-fish and shell-fish. It has been feared that due to gradual change in salinity profile of the estuary owing to the hydro-electric station established near the distal end of the estuary, the nursery grounds in mangrove environments are adversely affected. Yet another impact on the biota was due to the indiscriminate exploitation of river sand (Bhat *et al.*, 1988).

MANDOVI-ZUARI ESTUARINE COMPLEX (GOA)

Considerable work has been done on physical, chemical and biological characteristics of Mandovi-Zuari estuarine complex (Qasim and Sen Gupta, 1981). The source of high nitrate and nitrite in Mandovi estuary during premonsoon has been traced in the wastewater from an iron ore screening plant which discharged the muddy waste directly into the river (De Souza, 1983). Abnormally high levels of particulate and dissolved Fe (Kamat and Sankaranarayanan, 1975a and b) dissolved Mn and As have been attributed (Zingde *et al.*, 1976; Fondekar and Reddy, 1974) to the terrain rich in iron and manganese ores and mining operations. Increase in suspended solid content of bottom water and retrogressive changes

in the composition of the bottom deposits from 1972-73 to 1982-83 resulted in great deal of variations in population density and biomass in Mandovi estuary. A 44% reduction in the population density, 51% in the total benthic biomass and about 37% in species richness was found. The dominance of polychaetes and bivalves during 1972-73 was replaced by polychaetes and crustaceans indicating radical changes in fauna (Ansari, 1987). About 70% decline in the clam production from 1973 to 1983 in Mandovi estuary has also been attributed to the changes in the bottom deposits and suspended solids (Parulekar *et al.*, 1986).

ULHAS RIVER ESTUARY (MAHARASHTRA)

Ulhas River estuary which runs along the northern boundary of Bombay island receives variety of pollutants from a large number of industries scattered around its banks. It has been estimated that 18 major industries collectively released 11 t of Cu, 7 t of Pb, 400 t of Zn, 7 t of Hg and 0.5 t of Cr per year to the Ulhas River system. The receiving water was seriously contaminated making a stretch of about 24 km of the river till Kalyan-Bhivandi bridge dangerously polluted where anoxic conditions often prevailed (Sahu and Mukherjee, 1981). Even at Kasheli, the region of substantial tidal influence DO was subnormal except during August-September, the period of high riverine flow (Zingde *et al.*, 1979b). PO_4^{3-} -P and NO_3^- -N levels were abnormally high in the mid-estuarine stretch and fluctuated with the tide (Zingde, 1988a). The levels of trace-metals were relatively high in the water column as well as the sediments. Thus for instance, although the average background concentrations of Cu, Pb, Zn, Cr, Cd and Hg were 74, 13, 111, 155, 1.4 and 0.001 ppm in the sediments, their concentrations in the estuary were variable and typically exceeded 150, 100, 1000, 400, 2 and 10 respectively revealing the extent of sediment contamination by trace metals (Sahu and Mukherjee, 1981). The body burden of toxic metals in organisms was higher in the regions of influence of industrial waste. Bivalves, gastropods and polychaetes indicated relatively higher accumulation as compared to fish, crab and prawn (Srinivasan and Mahajan 1987). The fishery of the estuary has been adversely affected and some of the valuable species such as Bhing and Pala are no longer found in Bassein Creek (Mouth estuarine zone) where they were in abundance before. The small quantity of fish caught has been under priced because of bad odour (BMRDA, 1983).

DAMANGANGA RIVER ESTUARY (GUJARAT)

The wastewater (3200 m³/day) from the south sector of the industrial estate of Gujarat Industrial Development Corporation (GIDC) and a few other industries entered Damanganga below Vapi weir in the weak tidal zone. Although the flushing time of the estuary was estimated at only 6 tidal cycles, the waste released in the inner estuary had tendency to oscillate due to weak tidal influence in the zone of discharge except during spring tides. The acidic pH (2-4) of the wastewater decreased the pH of the receiving water though the effect was localised. The DO content of the inner estuary receiving BOD of 420 kg/day was dependent on the riverine flow over the weir. The freshwater flow with high DO not only diluted the effluent but also carried it to the lower estuary where tidal influence was appreciable. However, as the riverine flow decreased the water quality deteriorated and the DO levels were as low as 1 mg/

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1 in the inner estuary during April-May. High concentration of $\text{PO}_4^{3-}\text{-P}$ in the estuary (3-97 $\mu\text{g-at/l}$) was traced in the wastewater of a chemical industry (Zingde *et al.*, 1980b).

KOLAK RIVER ESTUARY (GUJARAT)

Major wastewater discharge in the river Kolak was from the north sector of the GIDC complex at Vapi and the wastewater from a paper mill. Both the discharges were in the weak tidal zone. In May the DO in the 4 km stretch of the estuary adjacent to the wastewater release points was below 0.5 mg/l and during April the levels were below 3.5 mg/l. Severe pollution conditions therefore existed in May. The whole area gave obnoxious smell and the environment almost became anaerobic with the evolution of hydrogen sulphide during May and early June. The conditions then became highly toxic to the aquatic organisms and the animals including fishes transported in this zone with the tidal water struggled and ultimately died. The concentrations of $\text{NO}_3^- \text{-N}$, $\text{NO}_2^- \text{-N}$, $\text{NH}_4^+ \text{-N}$, $\text{PO}_4^{3-}\text{-P}$ and phenolics revealed definite increase in the estuary as the freshwater flow decreased (Zingde *et al.*, 1980c).

PAR RIVER ESTUARY (GUJARAT)

A large industrial complex producing a variety of bulk and fine chemicals, dyes and dye-intermediates, pharmaceuticals and phosphorous pesticides released 30000 m^3/day of highly acidic wastewater in Par estuary just below the weir constructed to store freshwater for supply to the complex. The wastewater added 9700, 180, 50 and 57 kg/day of BOD, phenolics, nitrogen and phosphorus respectively, in the receiving water. Acidic pH (1.5-3.2) of wastewater controlled the pH of the estuary with large temporal and spatial changes. The high BOD considerably influences the DO which varied with the tide and the riverine freshwater flow (Zingde and Desai, 1987b). The low tide levels of 32 $\mu\text{g/l}$ of phenolics at the mouth of the estuary increased to 1050 $\mu\text{g/l}$ in the inner estuary.

AURANGA RIVER ESTUARY (GUJARAT)

The estuary received domestic waste (3200 m^3/day) from Bulsar city and wastewater (0.6 mld) from an industry manufacturing nitrocellulose. The shallow estuary was well mixed with excellent flushing characteristics with the flushing time of only 2.7 - 4.1 tidal cycles. The load retained in the estuary under continuous flow of pollutants after a large number of tidal cycles was estimated to be less than 3 times the load introduced per tidal cycle which was negligible. The estuary therefore exhibited good water quality (Zingde *et al.*, 1985b).

AMBIKA-KAVERI-KAREIRA ESTUARINE COMPLEX (GUJARAT)

Kaveri and Kareira Rivers join Ambika River near Billimora to form Ambika-Kaveri-Kareira estuarine complex (Zingde and Desai, 1987b). Kaveri received part of the untreated domestic sewage from Billimora town and 3800 m^3/day wastewater with high suspended load

and high BOD from a paper and pulp mill in the intermediate tidal zone. A textile mill manufacturing cotton and polyester fabrics released untreated wastewater (4800 m³/day) in the weak tidal zone of Ambika estuary. This zone also received 19.6 t/day of BOD through the wastewater (4300 m³/day) of a chemical complex manufacturing industrial alcohol, textiles and related products. Of all the estuaries in Gujarat State, Ambika received the highest BOD. A flushing time of 2.5 and 5.8 tidal cycles in October and May respectively has been reported for the estuarine complex (Zingde *et al.*, 1986).

The combined solids released through the wastewater amounted to about 12 t/day. Though this load was not very significant compared with the natural silt content in the water, it was mainly organic in nature and on settling on the estuary bed released obnoxious gases during low tide from the intertidal area. The surface sediments of the intertidal area receiving wastewater contained 3-6% organic carbon as against 0.5-2.5% in other locations of the estuary.

Low DO resulted in the mid-estuary around flood slack and high DO during ebb tide in October possibly because of accumulation of wastewater during flood tide due to opposing currents. The high riverine flow carried the wastewater downstream as ebb commenced resulting in low DO in the mouth region during low tides. Conditions became precarious in May when the riverine flow was weak. The maximum DO in the mid-estuary was only 1.8 mg/l and complete depletion was frequently observed. About 10 km stretch of the estuary had DO below 3 mg/l over 16 hr in a day in May indicating the severity of pollution in the estuary. The strong tidal currents then transported the wastewater further upstream in the estuary during high tide resulting in low DO and sometimes depletion of DO in the weak tidal region (Zingde *et al.*, 1986).

PURNA RIVER ESTUARY (GUJARAT)

Although Purna River estuary received only 11000 m³/day of wastewater imposing BOD load of 1.7 t/day, at least 5000 m³/day of this was released in the weak tidal zone. The flushing time of less than 2.5 tidal cycles, indicated that the load retained in the estuary after infinite number of tidal cycles was only 0.4 to 1.2 times the load introduced per tidal cycle. Nutrients, pH and trace metal concentrations in water did not seem to have been grossly affected by the wastewater inputs. Some influence was however observed on the dissolved oxygen content and BOD particularly in the inner estuary (Zingde *et al.*, 1987c).

MINDOLA RIVER ESTUARY (GUJARAT)

The waste from a variety of industries channelled through Udhna Khadi entered Mindola estuary at 10 km upstream from the mouth. The average flow of 95000 m³/day added a BOD load of 12.9 t/day. In addition several other industries also released their wastewater in the weak tidal zone imposing additional BOD of 3 t/day. The load retained in the estuary after a large number of tidal cycles under a continuous flow of pollutants would be 2.2 to 7.3 times the load introduced per tide cycle (Zingde *et al.*, 1988c). The organic load influenced

the oxygen balance in the estuary. There was a general tendency for DO to decrease with the ebb and values around 2 mg/l were observed during April in the mid-estuarine stretch. NH_4^+ -N was often high and varied widely in the estuary. Dissolved Cu and Zn revealed increase in concentration with decrease in salinity because of the greater impact of wastewater during low tides when the estuary volume decreased at least by 75% of the high tide value (Zingde *et al.*, 1988c). The fluoride added through the wastewater largely remained in solution resulting in significant deviation from the theoretical dilution line (Zingde and Mandalia, 1988d).

Comparative study of biomass and composition of zooplankton in Auranga, Ambika, Purna and Mindola estuaries revealed reduction in biomass and population density of certain groups in Ambika and Mindola estuaries which were more polluted than the other two (Nair *et al.*, 1981b). The benthic studies also revealed that Auranga had a higher population of biomass of benthos, Purna and Mindola contributed relatively moderate fauna and Ambika exhibited poor benthos both in terms of numerical abundance and biomass (Govindan *et al.*, 1983).

TAPI RIVER ESTUARY (GUJARAT)

Tapi and Narmada are the two major west flowing rivers in India. Information regarding the pollutants entering Tapi estuary is only fragmentary. Apart from a portion of the domestic wastewater from Surat city, the lower estuary received 20000 m³/day of wastewater from a fertilizer factory and 4000 m³/day from a gas fractionation plant. In view of rapid development of the region around, it is likely that the estuary would receive increasing quantities of wastewater in future.

Detailed studies undertaken in the estuary prior to the commissioning of the fertilizer and gas fractionation plants revealed very good water quality with DO in 7-10 mg/l range and low BOD (below 2 mg/l). The freshwater entering Tapi estuary was low in PO_4^{3-} -P (0.1 μg at/l) and NO_3^- -N (4 μg -at/l). Their concentrations however increased downstream with maxima centred in the mouth region suggesting regeneration of nutrients in this zone (Zingde *et al.*, 1987b). Levels of Ni, Cu and Zn in sediments also revealed natural background (Borole *et al.*, 1982). The overall biological characteristics of the estuary suggested moderate productivity (NIO, 1985).

NARMADA RIVER ESTUARY (GUJARAT)

Narmada estuary received domestic wastewater from Bharuch town and from industries at Ankleshwar in the upper estuarine region and wastewater from a fertilizer plant in the mouth estuarine zone. The investigations undertaken prior to the commissioning of the fertilizer complex have revealed very good water quality (Zingde *et al.*, 1981b) and high biological production potential of the estuary (NIO, 1980).

MAHI RIVER ESTUARY (GUJARAT)

The industries around Baroda released their wastewater of the order of $10 \times 10^4 \text{ m}^3/\text{day}$ in Mini Rivulet which transported the pollutants to Mahi at a point about 65 km upstream from the mouth which was just beyond the tidal zone. The wastewater devoid of DO had high concentration of ammonia and also contained sulphide. The wastewater release zone experienced poor flushing due to the presence of a rocky sill which obstructed the intrusion of tidal flood flow upstream. Evidently the waste accumulated in this stretch. The presence of high levels of nitrogen compounds in the wastewater resulted in high primary productivity often increasing the pH above the natural background particularly during the dry season (Zingde *et al.*, 1987b).

RUSHIKULYA RIVER ESTUARY (ORISSA)

A chloro-alkali industry primarily producing caustic soda by the classical Hg-cell method discharged Hg rich alkaline wastewater directly in the estuary. Dissolved Hg increased from $1.5 \mu\text{g}/\text{l}$ at the head of the estuary to $108 \mu\text{g}/\text{l}$ in the effluent discharge zone and decreased to $13.5 \mu\text{g}/\text{l}$ at the estuary mouth. Levels of 70-3500 ppm were observed in sediments of the mid-estuarine zone revealing the extent of sediment contamination (Sahu and Panda, 1987). Fish poisoning in the estuary and enhanced levels of mercury in flora and fauna of the region have been reported.

KRISHNA RIVER ESTUARY (ANDHRA PRADESH)

The estuarine system of Krishna river covers an area of 320 km^2 with its three tributaries Nadimeru, Golmuttapaya and Hamsaladevipaya. It is a mesotidal estuary with a tidal range of 2-3 m associated with strong currents of $1.2 \text{ cm}/\text{sec}$. Apart from mineralogy and geochemistry (Sarin *et al.*, 1985) not much information is available on the hydrography and environmental status of the estuary.

GODAVARI RIVER ESTUARY (ANDHRA PRADESH)

Godavari is a typical positive estuary with a mean width of 1.5 km and an average depth of 12 to 15 m. The estuarine sediments essentially consisted of mud with sand (10-40%) supplemented by silt and clay (Sarin *et al.*, 1985). Not much information however is available about the pollution loads and the water quality.

MAHANADI RIVER ESTUARY (BIHAR)

Several dams, barages, weirs and anicuts constructed along the stretch of this river have affected the outflow, consequently entrapping considerable amounts of nutrients, heavy metals etc. The nutrients indicated insignificant spatial but strong temporal variations. $\text{PO}_4^{3-}\text{-P}$ ranged from 0.53 to $4.01 \mu\text{g-at}/\text{l}$. $\text{NO}_3^- \text{-N}$ on the other hand revealed very wide range

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of variation with abnormally high levels (4.5 to 5.25 $\mu\text{g/at/l.}$) during monsoon associated with land drainage and precipitation. A comparatively high concentration of PO_4^{3-} and $\text{NO}_3\text{-N}$ in the mouth region indicated anthropogenic source of addition (Sen Gupta and Upadhyay, 1987). Faunal composition indicated mainly copepods and fish eggs and larvae. Larvae of penaeid prawns were abundant along the entire stretch of the estuary.

GANGA ESTUARINE SYSTEM (WEST BENGAL)

Not much published information is available on the water quality of Ganga estuary. The estuary however is considered to be polluted due to voluminous domestic and industrial wastewater released in the Hooghly estuary.

CONCLUSIONS

The overall assessment of the health of the coastal marine environment of India reveals that the coastal waters are by and large unpolluted except for some localised and severely to moderately polluted 'hot spots' adjacent to urban and industrial areas. However, many of the estuaries are showing signs of environmental degradation and some of them are severely polluted. Unfortunately, environmental studies in major estuarine systems of India are few and concentrated efforts are needed to evolve adequate master plan to protect them from deterioration.

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