

MARINE POLLUTION—WHAT ARE WE HEADING FOR?

M D Zingde

*National Institute of Oceanography
Mumbai 400 061, Maharashtra*

Unlike the open ocean, the coastal zone is the most affected and vulnerable to human abuse with several nearshore areas including well-flushed regions and enclosed and semi-enclosed seas getting increasingly polluted. This paper examines the trends that have emerged concerning the health of marine areas with particular reference to the coastal zone of India. Mangrove and coral ecosystems have been degraded and continue to be under stress of the man induced changes. Tourism related ecological degeneration is prevalent in several coastal segments though measures taken by the Government may arrest these trends, if enforced vigorously. Many major ports planned along the Indian coast some of which in ecosensitive areas, would eventually result in localised degraded regions if the present state of environmental management of most ports continues.

Indiscriminate release of liquid and solid wastes has degraded the ecology of localised inshore as well as openshore marine areas; the sewage, being the major contaminant. These waters are characterised by abnormally high and tide dependent levels of some nutrients, variable DO often falling to zero at low tides in some instances, widely fluctuating chlorophyll *a*, and zooplankton standing stock and abnormally high population of pathogens. The trends support increasing levels of $\text{NO}_3\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ along the central west coast of India and their utilization for primary productivity is suppressed perhaps by the high suspended particulate matter naturally occurring in these waters. The present impetus on coastal aquaculture and risk to which the culture stocks might be exposed, should a toxic bloom occur, requires implementation of a multilateral scientific research programme to systematically study the algal blooms. Scanty information on the levels of synthetic organics such as chlorinated hydrocarbon pesticides, polychlorinated biphenyls and polynuclear aromatic hydrocarbons as well as trace metals like lead, cadmium and mercury, suggests the necessity of long-term monitoring with a large area coverage to reliably identify the trends. Proposed establishment of refineries along the southern shore of the Gulf of Kachchh and eventual increase in the movement of crude oil and petroleum products highlights the urgent need of an adequately evolved environment management plan to minimise adverse impacts on the rich and diverse bioproductive regime of the Gulf. Likewise, accelerated efforts in offshore oil prospecting requires long-term systematic scientific monitoring of production as well as exploratory sites to identify trends in ecological modifications to tune the marine environmental management strategy. Predicted sealevel rise implies far sighted planning to identify vulnerable area and devise a long-term approach to coastal zone management that periodically reviews ground realities and incorporates modifications in the plan accordingly.

INTRODUCTION

Before considering futuristic health of the marine environment and how it would be closely linked with developments on land and human abuse of the seas, it is pertinent to look back a little and view the trends leading to the present state of the marine habitats. While, the pollution of freshwater, initially largely due to sewage, has been a matter of concern for centuries, the possibility that human activities could alter the basic properties of the seas resulting not only in contamination of marine biota but transfer poisons to seafood consumers causing even deaths, was highlighted by the Minamata incident in the 1950's. Further confirmation was provided by radioactive fallout over the global oceans due to the testing of nuclear weapons in the atmosphere and wide distribution of synthetic organic compounds, from the poles to the tropics, the source of which was clearly traceable back to human activities.¹ The extent of degradation in the marine environmental quality however, depends on several factors such as the type and the nature of the marine area receiving contaminants, the diversity and the variability of the ecosystem, the range of uses to which the area is put and the fluxes of pollutants it receives.

1. OPEN OCEAN

The main sources of contaminants to the open ocean are shipping and atmosphere apart from direct contribution by abyssal tectonic activity. Oil is the most common contaminant related to shipping resulting from deliberate discharges, though biocides leaching from the antifouling paints, accumulation of ship-related plastic debris and accidents are also of concern. The contaminants reaching the ocean *via* atmosphere include large amounts of desert sand and materials from volcanic activity and forest and grassland fires apart from those emitted to the atmosphere from evaporation, incineration and combustion processes. The available information, however, indicates that the levels of metals, synthetic organic compounds and oil are too low in oceanic waters for effects to be expected though bio-accumulation of some contaminants in oceanic biota is a well recognised fact. It is also fairly well established that present anthropogenic inputs of nutrients do not have any impact beyond the edge of the shelf.² Hence, with increasing public pressures to reduce emissions to the environment and regulations getting stringent, it is unlikely that the oceanic quality would be adversely affected in the immediate future.

2. COASTAL ZONE

The coastal zone consisting of the shallow waters and the intertidal areas alongwith the adjacent land mass, on the contrary, is the most affected as well as the most vulnerable to human abuse. This enhances the possibility of several nearshore areas including well-flushed regions and enclosed and

semi-enclosed seas such as the Baltic, Mediterranean and North Seas getting increasingly polluted, eventually spreading the damage even to the open ocean in the long run.³

This paper examines the trends that have emerged concerning the health of marine areas with particular reference to the coastal zone of India and assesses probable futuristic changes that might occur in the environmental quality. Scientific approaches required to understand these changes to design adequate mitigative measures are also discussed.

Apart from the published literature for which adequate references are given, much of the data pertaining to the coastal zone of India is derived from the data-base at this laboratory and the results of the National Programme "Coastal Ocean Monitoring and Prediction Systems" of the Department of Ocean Development. Admittedly, the available data-base is inadequate to recognise clear trends, nevertheless, a broad assessment is possible to identify issues requiring attention.

The primary factor driving coastal ocean degradation is the growth in human population that increasingly occupies the coastal space often modifying natural habitats, including mangrove forests, coral reefs, salt marshes and seagrass beds. Rapid depletion of mangrove areas at the rate of 5000 ha per year due to their use in wood chip industry in east Malaysia and conversion of 3200 ha of mangrove forests to farms are the examples of habitat destruction.³ Though the estimates of mangrove regions in India vary widely (3500-7500 km²), their large scale destruction and shrinkage in their habitats is well acknowledged. Mangroves of Gangetic Sunderbans, Andaman-Nicobar islands and Krishna, Kaveri and Godavari deltas which are some of the best mangrove formations of India have been degraded to a considerable extent.⁴ The fringing reefs with patches of live corals in the Gulf of Kachchh which are the most northerly in the Indian Ocean are under extreme stress leading to vast areas of dead corals due to increased Suspended Particulate Matter (SPM) as a result of mangrove deforestation and mining of coralline sand in the past.⁵ Coral reefs of the Andaman-Nicobar and Lakshadweep islands and Gulf of Mannar which sustain diverse ecosystems have shown decline in reef population, and an increase in coral diseases. Increase in SPM, quarrying of corals, destructive fishing methods and pollution have lead to their degradation.⁴

2.1 Tourism

With stress on international tourism that has increased pressures to open-up new locations for tourism development, pristine coastal regions are being developed as recreational beaches with associated commercial and domestic activities. These developments disturb traditional fisheries, interfere with marine life and eliminate nearshore habitats. Coastal belts of Goa, Maharashtra, Karnataka, Kerala and Tamilnadu offer many such instances of tourism related habitat degradation.

Several measures taken by the Government of India may however arrest these trends. The most important of these measures is the Coastal Regulatory Zone notification of 1991 (amended in 1997). Under this notification activities in the intertidal area and upto a specified certain distance inland from the high tide line are not permissible and developments adjacent to ecologically sensitive zones such as mangroves and coral reefs are strictly regulated. Other notable notifications are-

- (a) environment (Protection) (Amendment) Rules 1996,
- (b) environment Impact Assessment Notification (1994) and
- (c) notifications issued from time to time declaring certain areas as marine protected zones.

Atleast 15 marine regions including the portions of the Gulf of Kachchh, Gulf of Mannar, Palk Bay and Andaman have been declared as marine protected zones. In addition, several coastal segments are being brought under mangrove afforestation and if the present enthusiasm continues, the mangrove cover may stabilise and even improve in future.

2.2 Ports and Harbours

The development and maintenance of ports and harbours often create regions of degraded environment. Water exchange in these areas is generally restricted and contaminants including oily wastes, cargo escapement and sewage released from shipboard tend to accumulate in a port basin. In addition to activities within the basin itself, the ports in India have become the nuclei for setting of industries and settlements of human population. As a result, all major ports including Mumbai, Kochi, Chennai and Visakhapatnam invariably receive large volumes of non-port related domestic and industrial wastes leading to deterioration in their environmental quality which has reached alarming proportion in some cases.⁶

Several major ports are planned along the Indian coast some of which are in the ecologically sensitive areas of the Gulf of Kachchh, Vadhavan, Reddy and Tuticorin. If the present state of port maintenance continues, these coastal regions will end up into the undesirable centres of degraded environment to replicate the existing ports.

2.3 Discharges of Wastes

The coastal waters receive contaminants through a variety of pathways such as direct releases through outfalls and the loads transported *via* rivers, estuaries, creeks and bays. Surface runoff from agricultural areas, wash-out of agrochemicals and sediment resulting from coastal erosion or deforestation and desertification in the interland, also contaminate the marine zone. In addition, in most coastal cities the solid wastes including garbage is dumped in low lying areas and leachates, particularly during monsoon, enter nearby marine waters. The seriousness of the problem of solid waste disposal

can be gauged from the quantities generated in Mumbai which stand at 5000 t d⁻¹ of garbage, 2500 t d⁻¹ of debris and 500 t d⁻¹ of industrial waste. Contaminants from such sources include microorganisms, oxidisable organic matter, nutrients, trace metals, synthetic organic compounds, petroleum related compounds, SPM and heat.

2.3.1 Nutrients and Pathogens

Over 300 million people living in the coastal zone of India generate 11.1×10^9 m³ of sewage annually leading to wide-spread contamination of inshore and nearshore coastal areas particularly around coastal cities and towns. With limited treatment and disposal facilities, the domestic wastewater is largely released untreated to a nearby bay, creek or estuary imposing considerable strain on the receiving water.

By the year 2000, Mumbai city will be the second largest city of the world and there will be three Indian cities with a population of over 10 million. The Mumbai city with a human population density of 25000 km⁻² alone generates around 2.2×10^6 m³ d⁻¹ of domestic waste out of which about 2×10^6 m³ d⁻¹ enters the marine waters transporting high loads of contaminants (Table I) to the sea. In addition, the industries in and around the city release an estimated 2.3×10^5 m³ d⁻¹ of effluents-largely into the Thane, Mahim and Versova creeks and the Ulhas estuary.

Table I: Selected Contaminants Entering Coastal Waters of Mumbai Through Domestic Waste Water

Contaminant	Average concentration (mg l ⁻¹)	Load (kg d ⁻¹)
Dissolved solids	1800	3.6×10^6
SPM	235	4.7×10^5
BOD	280	5.6×10^5
Nitrogen	35	7×10^4
Phosphorus	6	1.2×10^4
Manganese	0.7	1400
Iron	2.1	4100
Cobalt	0.03	20
Nickel	0.08	160
Copper	0.10	200
Zinc	2.3	4600
Lead	0.05	100

These water bodies are characterised by abnormally high and tide dependant levels of PO₄³⁻-P, NO₃⁻-N and NH₄⁺-N, variable DO often falling to zero at low tides in some instances and abnormally high populations of pathogens (Table II). Often, the contaminated low salinity water from the interior creek draining into the outer bay during low tide, leads to distinct vertical stratification with the surface less saline water having low DO, low pH, high PO₄³⁻-P and low NO₃⁻-N. Interestingly, the levels of NO₃⁻-N and

Table II: Pathogenic Bacteria (no ml⁻¹) in Selected Coastal Areas

Bacteria type	Veraval		Versova Creek		Mahim Bay		Mumbai Harbour		3 km off Mumbai
	Harbour	3km off	^a F1	^b Eb	F1	Eb	F1	Eb	
Total Coliforms	414	13	600	1900	49	1100	70	100	42
<i>Escherichia</i> like organisms	247	6	100	400	29	200	-	-	17
<i>Shigella</i> like organisms	5	-	1700	2600	29	1300	30	40	26
<i>Salmonella</i> like organisms	21	-	-	700	9	300	-	-	-
<i>Proteus klebsiella</i> like organisms	90	4	200	3900	44	1600	20	120	7
<i>Vibrio</i> like organisms	218	31	3200	1700	32	2200	20	60	36
<i>Vibrio parahaemolyticus</i> like organisms	25	2	-	600	-	400	-	-	-
<i>Vibrio cholerae</i> like organisms	8	-	600	800	20	600	10	60	14
<i>Pseudomonas aeruginosa</i> like organisms	79	6	-	-	20	-	-	-	-
<i>Sireptococcus faecalis</i> like organisms	194	-	4600	1700	122	600	20	70	2

^aF1 : Flood tide; ^b Eb: Ebb tide

NO_2 -N decrease substantially when DO decreases below 1mg/l suggesting active denitrification.⁷ Marked increase in concentrations of nutrients, decrease in DO and abnormal enhancement in levels of chlorophyll *a* and zooplankton biomass in the inner Ulhas estuary is clearly evident⁸ from Fig. 1. Though Thane creek receives high loads of wastewaters, the conditions are not severe as in other creeks due to large volume of the receiving water and good tidal flushing with a mean tidal range of 3.30 and 4.42 m during spring and neap tides, respectively. The levels of pathogens are abnormally high in the interior creek and decreases substantially in the outer creek (Mumbai harbour). Considerable reduction in the populations also occurs at the high tide due to dilution effect.⁸ Nevertheless, at concentrations occurring in the inshore and nearshore coastal waters of Mumbai, they could be a health hazard to the swimmers and their association with fish and shellfish is a distinct possibility.

Varying degrees of environmental degradation occur from severe as in the case of Mahim creek to moderate as in Mumbai harbour, in a large number of inshore water bodies along the west as well as the east coasts of India. Notable examples are Veraval and Porbandar harbours, Mahi, Mindola, Purna, Par, Ambika, Auranga, Damanganga, Ulhas and Ashatmudi estuaries and interior Kochi Backwaters along the west coast and Paradeep, Visakhapatnam and Chennai ports and interior Hoogli and Rushikulya estuaries along the east coast.⁶ The impacts of contaminants are however generally confined to the receiving waters and conditions appear to be normal⁸ off the coast as in the case of Veraval (Table III) though nutrient enhancement; NO_3 -N in particular, is evident in some instances such as the coastal segment between Bassein and Thal (Table IV). A five fold increase in the level of NO_3 -N has also occurred in the Gulf of Khambhat over the past 25 y perhaps due to the loads brought-in by a number of rivers which predominantly drain agricultural and forest areas in their hinterland. It is however evident that the chlorophyll *a* content of the coastal waters of these areas has remained static though NO_3 -N has increased substantially and PO_4^{3-} -P is also available. It is possible that the high natural SPM in these waters hinders photosynthesis. The build-up of NO_3 -N in water would therefore increase which would slowly diffuse further off the coast where primary productivity may increase in the absence of high SPM which may lead to eutrophication in extreme cases. Such a situation may result in increase in DO levels in the surface waters from its production in the photosynthetic process and depletion in deeper waters from its involvement in respiration. This has serious implications particularly for fishery since subsurface water mass in the Arabian Sea is deficient in DO and an increase in organic matter can potentially decrease the thickness of the DO rich surface layer. Similar conditions have been observed in several regional seas; the Baltic and Adriatic Seas are the notable examples.^{9&10}

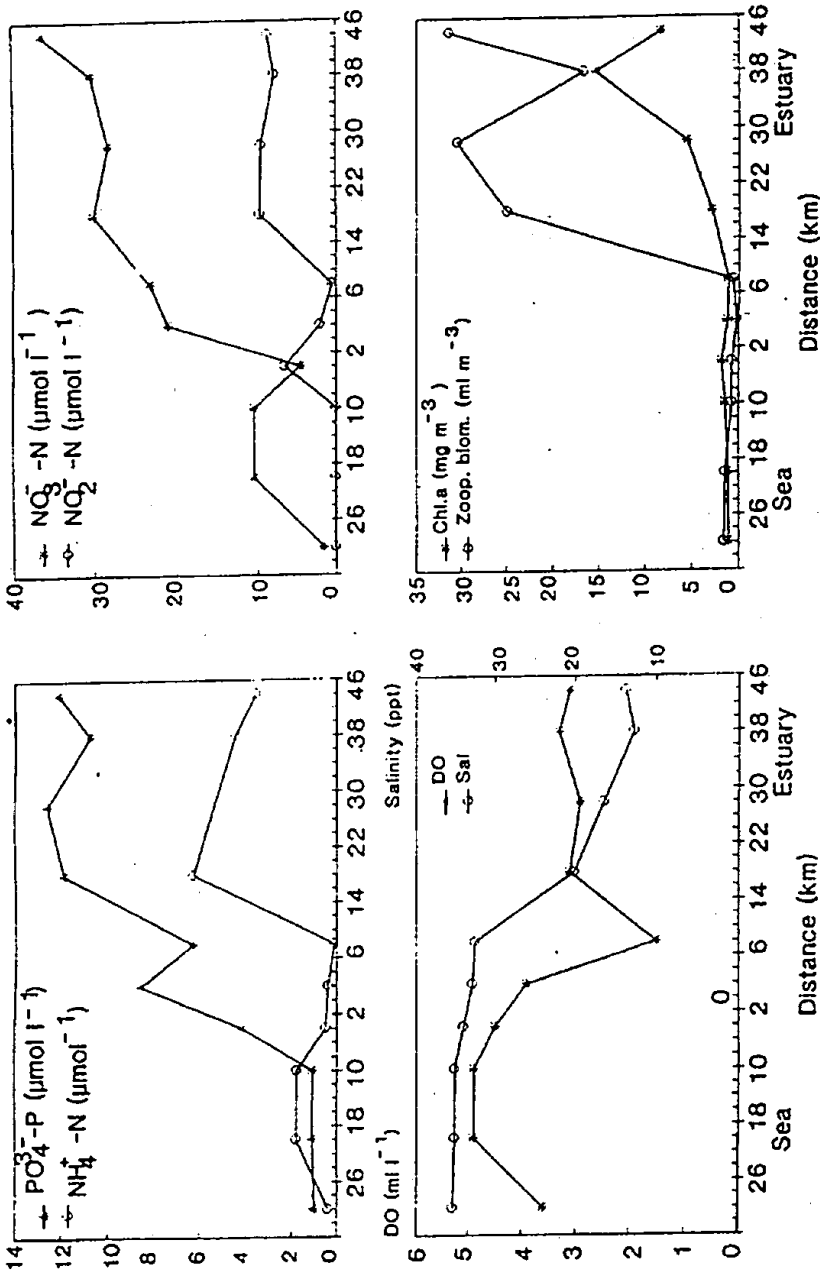


Figure 1. Variation of DO, salinity, nutrients, chlorophyll a (chl.a) and zooplankton biomass (Zoop.biom.) along Ulhas estuary and adjacent coastal water. Zero on the distance axis represents the estuary mouth.

Understanding the course of subtle changes in a large water body such as the coastal Arabian Sea requires a long-term commitment over a time scale of decades and monitoring programme involving a large area designed to detect small changes superimposed over natural variations inherent to marine waters.

Table III: Ecological Status of Veraval^b

Parameter	Harbour	3km off
Salinity (ppt)	34.8 - 35.9	35.9 - 36
SPM (mg l ⁻¹)	30 - 62	15 - 20
pH	7.6 - 7.9	8.1
DO (ml l ⁻¹)	0 - 3.2	2.8 - 3.9
PO ₄ ³⁻ -P (μmol l ⁻¹)	2.2 - 16.1	1.1 - 1.6
NO ₃ ⁻ -N (μmol l ⁻¹)	0 - 14.1	14.8 - 20.8
NO ₂ ⁻ -N (μmol l ⁻¹)	0.5 - 3.5	0.4 - 0.7
NH ₄ ⁺ -N (μmol l ⁻¹)	21 - 67	0.1 - 0.4
Chlorophyll <i>a</i> (mg m ⁻³)	1.1 - 3.7	0.5 - 1.6
Zooplankton biomass (ml m ⁻³)	0.1 - 5.3	5.0 - 6.7

In order that the relevant and essential data can be collected more economically and reliably, novel approaches are needed, perhaps involving the use of satellites as well as moored and drifting buoys.¹⁰ In fact, eutrophication of shelf waters and regional seas is of global concern today and in some locations increase in fertility has resulted in changes in the structure of planktonic and benthic communities often with substantial ecological and economic consequences.² An increase in number of episodic events of exotic algal blooms, popularly called red tides, is considered to be due to eutrophication though there is no direct evidence. These phytoplankton may harbour highly toxic poisons that can cause death to marine organisms and even humans. Cases of algal blooms leading to human death as in the case of Amnesic Shellfish Poisoning (ASP) in Prince Edward Island in 1987 and Neurotoxic Shellfish Poisoning (NSP) in New Zealand have been well documented. Red tides have also caused massive destruction of farmed fish in Japan and France.¹¹ Such large scale toxic algal blooms have not been reported in the coastal waters of India perhaps because of lack of scientific documentation, though occurrence of such events could be of concern particularly because of expansion and intensification of shrimp farming in recent years. Red tide phenomenon, however, is known to occur in the Arabian Sea and to a lesser extent in the Bay of Bengal though systematic studies to identify the factors triggering the growth of phytoplankton are lacking.¹² The present impetus on coastal aquaculture and risk to which the culture stocks might be exposed, should a toxic bloom occur, requires implementation of a multilateral scientific research programme to study such blooms, document toxicity levels of phytoplankton species and conditions under which excessive production is triggered.

Table IV: Variation of Marine Environmental Quality at Some Coastal Locations (Dry Season)

Parameter	Gulf of Khambat		Tapi Estuary			Thal		
	1979	1995	1985	1989	1997	1980	1990	1996
pH	8.0	8.0	8.0	8.0	8.0	8.1	8.0	7.9
SPM (mg l ⁻¹)	-	500	300	250	300	150	240	200
DO (mg l ⁻¹)	7.3	6.6	6.0	4.5	2.5	4.2	4.2	3.5
PO ₄ ³⁻ -P (μ mol l ⁻¹)	1.5	1.6	2.1	2.5	3.0	1.1	1.5	3.8
NO ₃ ⁻ -N (μ mol l ⁻¹)	5	25	10	50	55	4.3	13.7	14.9
NO ₂ ⁻ -N (μ mol l ⁻¹)	0.2	0.1	1.5	2.5	5.5	0.9	9.3	0.5
NH ₄ ⁺ -N (μ mol l ⁻¹)	2.5	0.5	0.5	2.0	1.5	2.1	1.3	0.6
Chlorophyll a (mg m ⁻³)	1.8	1.3	1.5	2.0	1.5	2.7	2.9	1.5
Zooplankton biomass (ml m ⁻³)	2.2	1.9	2.5	1.8	1.7	9.6	13.4	12.8

In a conscious attempt to relieve the inshore waters of sewage related stress, the major fraction of domestic wastewater generated in the Mumbai city will be released in the open sea through massive marine outfalls about 3 to 4 km from the shoreline, after primary treatment. While this strategy will undoubtedly improve the health of creeks, bays and estuaries around, the load on the coastal water will increase several folds. As the first coastal outfall is expected to be operational by early 1999, a comprehensive scientific study is required to be planned and commissioned forthwith to evaluate the ecological changes in comparison with the predisposal conditions. The results will undoubtedly, be useful while commissioning similar marine outfalls elsewhere along the coast.

2.3.2 Industrial Contaminants

Major sources of industrial chemical discharges are paper and pulp mills, sugar factories, distilleries, iron and steel works, dye industries, petroleum refineries, petrochemical industries, fertilizer factories, leather tanning and finishing and other chemistry based production centres including pharmaceutical establishments. The wastewaters of these industries are often complex, and without appropriate treatment and properly located outfalls can cause immense damage to ecology, though on a localised scale. It is often argued that wastewater when treated to meet pre-set criteria such as those prescribed by the pollution control boards, the safety of the marine environment is automatically assured. This is far from reality since only gross parameters such as BOD and COD are included in the standards, which account for overall oxidisable organic matter. The wastewater may contain several organic compounds, some of which at trace levels, but toxic. The overall BOD and COD may fall within the acceptable standards yet these compounds if not removed, may be harmful.

A group of chemical contaminants of serious concern are those synthetic organic compounds that can accumulate to relatively high concentrations in areas of restricted water exchange and include chlorinated hydrocarbon pesticides (DDT and its metabolites, chlordane related compounds, HCH, Aldrin, Dieldrin, Endrin), Polychlorinated Biphenyls (PCBs) and Polynuclear Aromatic Hydrocarbons (PAHs). Though the persistent halogenated hydrocarbons do not adversely affect the lower organisms in the sea, they are hazardous to predators which accumulate residue in fatty tissues as observed among the populations of marine mammals and birds of the Baltic and Wadden Sea regions.¹⁰ However, as a result of ban and restrictions on the manufacture and/or use of several organochlorines, downward trends in concentrations in seawater and in organisms have emerged. A general decrease in the concentrations of total DDT in oyster from the northern Gulf of Mexico from 1986 to 1993 has been attributed¹³ to the restrictions on the use of DDT in 1978 and ban since 1982, in USA. The levels of *cis*-chlordane and *trans*-nonchlor in oysters from the Naples bay (South Florida)

have also shown decline from 50-65 $\mu\text{g g}^{-1}$ (dry wt.) in 1986 to below 15 $\mu\text{g g}^{-1}$ (dry wt.) in 1995.¹⁴ The concentrations of PAHs however have not recorded a decrease from 1986 to 1992 perhaps since their inputs to marine environment have not declined in the absence of any restrictions on their entry in the sea.

Reliable information on the levels of this group of chemicals is largely lacking for the waters around India though several reports on the levels of DDT and Aldrin have been published.^{15&16} Roughly 25000 t of chlorinated pesticides used annually in India about 50 t of DDT are transported to the Arabian Sea and Bay of Bengal every year through river discharge.¹⁵ Pronounced variations in DDT and Aldrin levels, closely reflecting the pattern of use on land occur in zooplankton before and during southwest monsoon season in the Arabian Sea. In the case of fish, accumulation of these pesticide residues is influenced by their feeding habits (and habitat). Further research is clearly required to understand the significance of such seasonal and species related variations in the accumulation of the conservative pesticides by the marine organisms of the Arabian Sea and Bay of Bengal. The present trend of decreasing use of chlorinated pesticides in India may however result in decrease in their concentration in the components of marine environment, in future. Nevertheless, long-term monitoring with larger area coverage and many more species is required to establish trends apart from investigating levels of other chlorinated pesticides, PCBs and PAHs for which the information is scanty.

Another group of contaminants of concern are heavy metals, particularly Pb, Cd and Hg and to a lesser extent Cr, Ni, Cu, Zn and As. Their concentration in the coastal water of India are low and in the range expected for unpolluted waters.³ Their levels in the coastal sediment in general result from the lithogenic contribution⁸ though some localised inshore areas, particularly those receiving industrial and domestic effluents have shown increase in their concentrations over the years. Thus for example, a sediment core from the Mahim creek reveals high accumulation of C, P, Cr, Pb, Cd and Zn (Fig. 2) in the segment above 50 cm from the bottom⁶ which has presumably deposited in the post-industrialized period. The Mn profile of increasing concentration with depth in this core is typical of the anoxic sediment environment that reduces Mn^{4+} to more soluble Mn^{2+} which leaches in the interstitial fluid and eventually escapes to the overlying water. An increase in Pb and Hg in the surficial sediment of Ulhas estuary⁸ is also evident from Fig. 3. Similarly the levels of several heavy metals in the surficial sediment of Visakhapatnam harbour have increased several folds in comparison with the corresponding concentration in the coastal sediment outside the harbour bay.¹⁷

Conversely, decrease in sediment contamination by heavy metals due to decrease in their fluxes because of increasing treatment given to the effluent for their removal has also been noted. This is evident from the

profile (Fig. 4) of Hg in a sediment core from Par estuary¹⁸ which has shown a systematic decrease from the bottom to the top. The Par estuary has been receiving untreated effluents containing Hg from a chemical complex prior to 1970's. The level in the effluent decreased progressively as the effluent received treatment in stages since 1980.

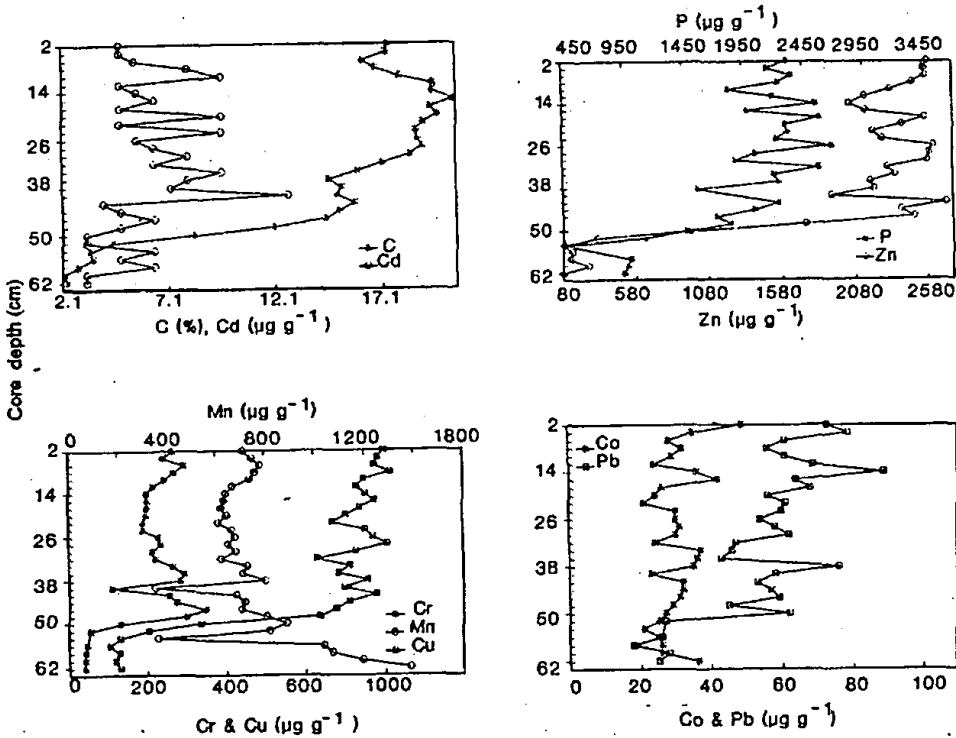


Figure 2. Depth profiles of C, P, Cr, Mn, Co, Ni, Cu, Zn, Pb and Cd in a sediment core from Mahim creek (Concentrations on dry wt. basis).

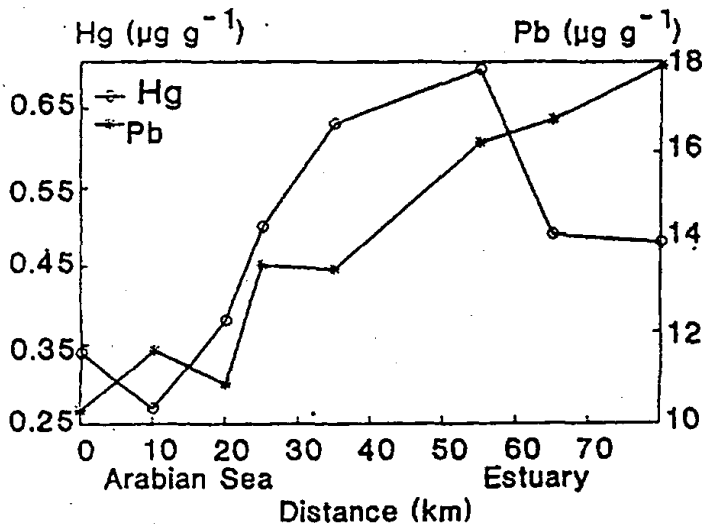


Figure 3. Hg and Pb in surficial sediment of Ulhas estuary and adjacent coastal water (concentrations on dry wt. basis).

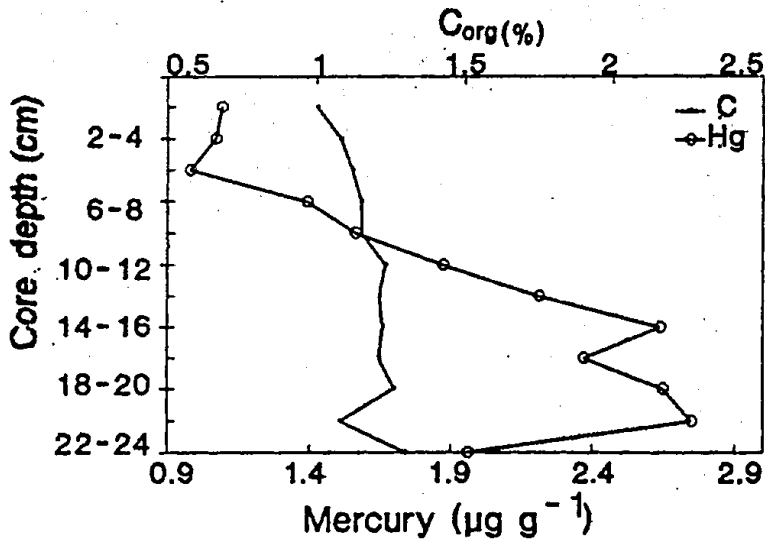


Figure 4. Depth profiles of C_{org} and Hg in a sediment core from Par estuary (concentrations on dry wt. basis).

Available literature indicates that although in a few cases of abnormal concentrations of some toxic metals in marine organisms localised to waste receiving sites, the commercial fish and shell-fish is by and large free from heavy metal contamination.³ The data, however, is fragmentary restricted to a few species and limited to select areas. A long-term monitoring programme such as the 'Muscle watch' should therefore be designed involving monitoring polluted, vulnerable as well as clean coastal areas with a wide spread geographical coverage and commissioned, if the trends are to be identified.

2.4 Oil Pollution

The Arabian Sea and Bay of Bengal have been estimated to receive 5×10^6 and 4×10^5 t respectively of petroleum annually due to routine discharge of ballast waters, bilge slops and tank washings from oil tankers and other ships plying the shipping lanes of the Indian Ocean. Consequently, tar balls and oily residues are a common sight on most beaches bordering the Indian Ocean including India. Damage to coral reefs of Andaman and Nicobar islands due to coating with oil residues has also been reported.¹⁹

With the consumption of petroleum products in India increasing from 5.5×10^7 t during 1990-91 to 8.82×10^7 t during 1997-98 and yearly domestic production remaining nearly stagnant at around 3.3×10^7 t, it has become inevitable to increasingly import crude oil and its products thereby exposing the coastal segments to oil pollution. Moreover, accelerated efforts in offshore oil prospecting in several areas of the continental shelf further enhances the vulnerability of the coastal zone to oil induced degradation. Available records indicate that about 590 exploratory wells and 930 development wells

have been drilled along the west coast; the respective numbers along the east coast being 175 and 12. Exploration and production sites generate considerable volume of solid and liquid wastes and typical quantities have been fairly well established.¹⁹ Using these data, it is estimated that exploratory and production wells all put together would have discarded roughly 4.2×10^7 t of drilling mud and 4.7×10^7 t of rock cuttings on the continental shelf. Dumping of drilling muds and rock cuttings have potential to increase the levels of Hg, Cr, Zn, Cd, Cu, Pb, Ni and Ba in water apart from adding oil to the environment.¹⁹ Moreover, about 25 production platforms operating along the west coast would be adding approximately 2 t d^{-1} of oil through the releases of production water in addition to other dissolved organic compounds, trace metals, chemical additives used in petroleum production process and SPM. This estimate is based on the presumption¹⁹ that a production platform generates about $1500 \text{ m}^3 \text{ d}^{-1}$ of production water with an average oil content of 50 mg l^{-1} . The impacts of all these contaminants on marine ecology of offshore production sites however, has not been systematically studied though a report²⁰ indicates a trend of increasing levels of nutrients and petroleum hydrocarbons and decrease in DO in the water of Bombay High.

Systematic scientific monitoring of production as well as the exploratory sites designed to identify trends in ecological modifications induced by oil prospecting activities should therefore be taken up. The emerging results should be utilized to tune the marine environmental management strategy, if required. This is all the more important since many virgin marine areas are being presently explored for oil and many more will join the group in near future.

Another concern arises from an inevitable increase of import of crude oil through very large crude carriers and their unloading *via* single point moorings to feed the grass-root refineries under construction on the southern bank of the Gulf of Kachchh and a few in the hinterland. Moreover, apart from the projected increase in the traffic of petroleum at Kandla port, the products manufactured by these coastal refineries will also be evacuated to a large extent via the Gulf. The present import of crude oil alone which is around $1 \times 10^7 \text{ t y}^{-1}$ has been estimated to increase to over $6 \times 10^7 \text{ t y}^{-1}$ over the next decade which will expose the Gulf which is biologically the most productive habitat along the west coast of India harbouring diverse flora and fauna such as seaweeds, seagrasses and mangroves and a variety of sponges, sea anemones, corals, fish and shell fish, to ecological degradation if proper environment management plans are not evolved and earnestly implemented.²¹

No major oil spill has occurred along the Indian coast, however the experience of combating a medium spill variously estimated between 1500 and 6000 t in Bombay High that resulted on 19 May 1993 left lot to be desired. Although 10 days were available to recover the spilled oil, before it reached the shore, about 1000 t of the oil residue mixed with debris polluted

at least a 5 km stretch of the coastline around Murud revealing inadequacy of the then employed oil spill combating strategy.²²

Further, deliberate illegal discharges of oil which can vary from a few litres to a few tons pose a chronic threat to the coastal ecology which will increase with projected increase in the petroleum traffic. In order to minimise, if not eliminate considerable political, economic and environmental repercussions due to oil spillages, it is necessary to suitably augment the National Oil Spill Disaster Contingency Plan by incorporating systematic surveillance capability, immediate reporting of all oil spills and prompt and efficient response counter measures on the lines practiced in many western countries.²³

2.5 Sea Level Rise

It is believed that the sea levels averaged globally are rising by about 3 mm y⁻¹ due to increasing concentration of green house gases in the atmosphere, that may have serious consequence for several nations. Current projections predict²⁴ a rise of 8 to 29 cm by 2030 and between 66 and 110 cm by 2100. If this happens, the coastal areas of India vulnerable to sealevel rise will experience increased flood damage due to storm surge, shoreline retreat, high wave activity and increased land subsidence apart from ecological effects including loss of coastal wetlands, coastal habitats, coastal vegetation and nearshore cultivable lands.

An economic impact study of 1m sea level rise on India has concluded that the economic vulnerability of the Indian coastline in present value terms²⁵ ranges from Rs. 2287 billion in the case of Mumbai to Rs.3.3 billion in the case of Balasore. Some coastal activities are vulnerable to sea level rise while there are others that aggravate the vulnerability of the area to sea level rise. Hence, prevailing policies of permitting developments close to the shore at the expense of coastal vegetation and sand dunes require to be reviewed seriously. In fact, proper mitigative strategy requires far sighted planning to identify areas vulnerable to sea level rise and an adequate long-term coastal zone management approach that periodically reviews ground realities and incorporates modifications in the plan accordingly.

REFERENCES

1. A.D. McIntyre, (1995). *Mar. Pollut. Bull.*, 31, pp. 147.
2. IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) *Rep. Stud. GESAMP NO 39*, (1990), pp. 111.
3. R. Sen Gupta, M. Ali, A.L. Bhuiyan, M.M. Hussain, P.M. Sivalingam, S. Subasinghe and N.M. Tirmizi, (1990). *UNEP Regional Seas Report and Studies No 123*, pp. 42.
4. V.K. Sharma, P. Tiwari and R. Jaiswal, (1997). Environmental and socio-economic problems of the coastal ecosystem in India: A focus on Mumbai In: *Coastal Cities in India: Responding to Environmental and Socio-economic Issues of Concern* (Ed. V K Sharma) Indira Gandhi Institute of Development Research, Mumbai, pp. 17.

5. *Marine Environmental Impact of Proposed Refinery Complex at Moti Khavdi* National Institute of Oceanography, Mumbai (1995), pp. 106.
6. M.D. Zingde, (1989). Environmental status of the coastal marine environment of India In: *Management of Aquatic Ecosystems* (Eds. V P Agarwal, et al.) Society of Biosciences, Muzaffarnagar, pp. 37.
7. M.D. Zingde and M.M. Sabnis, (1994). Pollution induced tidal variability in water quality of Mahim estuary In: *Environment and Applied Biology* (Eds. V P Agarwal, et al.), Society of Biosciences, Muzaffarnagar, pp. 277.
8. *Marine Environmental Studies: Environmental Quality Along the North-West Coast of India*, National Institute of Oceanography, Mumbai (1997).
9. *IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) Rep Stud GESAMP No 16*, (1982), pp. 108.
10. E.D. Goldberg, (1995). *Mar. Pollut. Bull.*, **31**, pp. 152.
11. D.M. Anderson, (1994). *Scient. Am.*, pp. 62.
12. V.P. Devassy, (1987). Trichodismium red tides in the Arabian Sea In: *Contributions to Marine Sciences* (Ed. T S S Rao, R Natarajan, B N Desai, G Narayana Swamy and S. R. Bhatt) National Institute of Oceanography, Goa, pp. 61.
13. J.L. Sericano, T.L. Wadi, T.J. Jackson, J.M. Brooks, B.W. Trip, J.W. Farrington, L.D. Mee, J.W. Readmann, J.P. Villeneuve and E.G. Goldberg, (1995). *Mar. Pollut. Bull.*, **31**, pp. 214.
14. A.Y. Cantillo, G.C. Lauenstein and T.P. O'conner, (1997). *Mar. Pollut. Bull.*, **34**, pp. 511.
15. M.S. Shailaja and M. Nair, (1997). *Mar. Env. Res.*, **44**, pp. 263.
16. K. Kannan, S. Tanabe and R. Tatsukawa, (1995). *Env. Sci. Technol.*, **29**, pp. 2673.
17. D. Satyanarayana, P.K. Panigrahy and S.D. Sahu , (1994). *Indian J. mar. Sci.*, **23**, pp. 52.
18. A. Ram and M.D. Zingde, (1997). Mercury accumulation in sediment of Par estuary *Abstracts, Seminar on Industrial Effluents and Coastal Pollution*, Goa University, Goa, pp. 8.
19. *IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) Rep Stud GESAMP No 50* (1993), pp. 180.
20. M.A. Rokade, (1994). Some aspects of pollution of coastal marine environment of Bombay *Ph.D. Thesis* University of Mumbai, pp. 61.
21. M.D. Zingde and N.M. Anand, (1994). Implications of coastal refineries to the ecology of the Gulf of Kachchh In: *Proce. nat. Symp. Ocean and Industry - Realities and Expectations* (Ed. P S Srivastava) Society of Ocean Scientists & Technologists, New Delhi, pp. 67.
22. *Assessment of Oil Spill of 17th May 1993 on Coastal Marine Environment of Murud*, National Institute of Oceanography, Mumbai (1993), pp. 29.
23. J.P. Pedersen, L.G. Seljelv, T. Bauna, G.D. Strom, O.A. Follum, J.H. Andersen, T. Wahl and A. Skoelv, (1996). *Spill S & T Bull*, **3**, pp. 41.
24. *Climate Change - The IPCC Scientific Assessment*. Report prepared by IPCC Working Group 1, Cambridge University Press, Cambridge (1990).
25. L. Noronha, (1997). Oceans.: need for an awareness In : *Proce. nat. Sem. Coastal Ocean Regime and Developing Countries* (Ed. H P Rajan) Department of Ocean Development, New Delhi, **10**.