

Marine Pollution Levels and Potential Threats to the Indian Marine Environment : "State of the Art"

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Preamble

A decade of marine pollution investigations starting with the commissioning of the first full fledged oceanographic research vessel "*Gaveshani*" in February 1976 and subsequently of another research ship "*Sagar Kanya*" in June 1988 has given us a wealth of data in assessing (in broader terms), the "*Health of the seas around India*". This has provided the impetus to marine pollution research in India through the concerned efforts of National Institute of Oceanography along with its regional centres in Bombay, Cochin and Waltair. The need for such investigations arises from the fact that India has a very long coastline of more than 6000 km with an exclusive economic zone covering an area of about 2.015×10^6 km². A large section of Indian population, roughly about 25% or 180 million people, live in the coastal areas depending directly or indirectly on the coastal resources and in turn generating and releasing domestic sewage of the order of 3.3 km³ annually to these waters. Qasim and Sen Gupta (1983), had given the amount of various pollutants reaching the Indian coastal environment which was modified in 1984 giving the figures of 5×10^6 tonnes of fertilisers, 55,000 tonnes of pesticides and 125,000 tonnes of synthetic detergents as total amounts used in India. It is estimated that nearly 25% of all these ultimately find their way into the marine environment. The principal routes of this transfer are rivers, atmosphere and direct discharge (sewage and industrial effluents).

In broader perspective it would be unwise to term environmental contamination as an amoral phenomenon. It is the inevitable consequence of the activities of man and a natural phenomenon as well. To elaborate this point it can be said that man

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has characterised his activities by disposing of waste materials, partially used consumer goods and other byproducts into the environment whether it is an industrial society or an agricultural one. Added to this, the natural process of the world around us causes continuous change by removing, replacing and redistributing an enormous volume and variety of material, thus constantly contaminating and decontaminating itself. Contamination must therefore be considered, in the light of these points, neither right nor wrong, but merely a consequence of living. Excessive contamination, however, resulting from indiscriminate use and discharge of polluting materials into the environment interfering with the health and happiness of a population, could be termed as *pollution*. The scientific definition thus derived by the *Group of Experts on the Scientific Aspect of Marine Pollution (GESAMP)* is :

"The introduction by man, directly or indirectly, of substances or energy i to the marine environment (including the estuaries) resulting in such deleterious effects as harm to, living resources, hazards to human health, hindrance to marine activities including fishing, improvement of quality for use of sea water and reduction of amenities."

Keeping this self-explanatory definition in mind it becomes clear that effective management of contamination, whether natural or man-made, so that it does not become "pollution", is essential for us to develop but agriculturally and industrially. A rational management programme, designed to avoid adverse effects from contamination, starts with the recognition, description and understanding of the effect of the contaminants themselves.

Johnston (1976) has characterised three broad categories of marine pollutants namely native or natural which are not caused by man, generated by man but not created by him and the synthetic pollutants wholly created by man. One can broadly put hydrocarbons, soluble inorganic and organic substances in the first category; redistribution and exploitation by man of these hydrocarbons etc. in the second and plastics, radionuclides and pesticides (DDT, BHC, etc.) in the third.

Population and related data for India and some estimates of pollutants entering the seas around India (as of 1984) is given in Table I. It is clear from this table that a considerable amount of polluting substances are added to the Indian seas annually and if we add natural addition like atmospheric inputs or weathering inputs to it (for which there are no definite data) the situation looks quite alarming. In this article we will discuss the present state of affairs taking each group of pollutants and their levels in the seas around India.

Domestic sewage

Domestic sewage, in small proportions, fertilises the sea water and increases the rate of productivity, but over fertilization adds pressures on the marine environment resulting in eutrophication. This leads to excessive growth of algae which becomes detrimental to the systematic productivity processes. In other words, excessive amounts of sewage (nutrients) change the algal community and induce artificial diversity of species ranging from one to a few species. In such a situation commonly the herbivorous species thrive. Often the blooms of the blue-green algae or manoplank-

ton, totally unsuitable as food for the grazing animals, may create environmental problems. Thus, the changes in the plant population causes changes throughout the ecosystem, and even in the availability of organisms which form higher links in the food chain. From such an analysis it is clear that if photosynthetic productivity is in a form which can be readily consumed, it will favour the production of higher forms of life. It remains unconsumed, as it has been noticed in the case of *Noctiluca*, *Gonyaulax*, *Irichodesmium* etc. and it can create serious environmental problems (Qasim and Kureishy, 1986).

Moreover, an excess of sewage discharge also effects the oxygen concentrations in water and may lead to anaerobic conditions. Thus, in the Arabian Sea where, low concentrations of oxygen are naturally occurring, the additions of large volumes of sewage may alter the oxygen balance at the sub-surface where it may presumably become difficult for living beings to survive.

The results of this discharge are not very perceptible all over the Indian coast, as yet, however off the coasts of a few metropolitan cities with heavy industrial base the effects are indeed becoming obvious. Sen Gupta and Sankaranarayanan (1975) observed an increase by about 40% ($0.82-1.13 \mu \text{ mol. l}^{-1}$) of phosphate-phosphorous concentrations from 1959 to 1974 in the nearshore waters of Bombay. More recent observations reveal a concentration of around $2.0 \mu \text{ mol. l}^{-1}$ (Zingde, Personal communication). Similarly dissolved oxygen concentrations also show negative trend from 4.71 ml/l in 1959 to near zero in 1983 (Parulekar, Personal communication). Sen Gupta, in yet unpublished data, also observed high values of phosphate-phosphorous in the nearshore waters of Madras, as compared to earlier values. These increases can very well be an indication of the uninterrupted and untreated discharge of sewage and other effluents. Sabnis (1984) came to a figure of 3.5 million tonnes as total volume of all discharges from Bombay city alone every year. A similar figure of around 350 million tonnes was given by Ghosh *et. al.* (1973) as discharges from the environs of Calcutta city. These figures give an idea of the total volume of domestic sewage, industrial effluents and other wastes, which are discharged to the coastal waters of India.

The Mahim Bay in the city of Bombay is an example for such contamination. This bay occupies an area of 64 km^2 and is influenced by a semi-diurnal tide with a maximum height of 8 m. Sabnis (1984) gave the details of the annual discharges to this bay which is presented in Table II. The Bay receives 64 MT (metric tonnes) domestic sewage apart from other substantial discharges which are now being partially treated. Thus an area, which once was a healthy ecosystem with good fisheries, oysterbeds, fringing mangroves etc. and visited by migratory birds, became one of the most polluted ecosystems in the country. The resulting H_2S concentrations range from $1.5-98.4 \mu \text{ mol. l}^{-1}$ depending on the stages of the tide. This is a clear example of how uncontrolled discharges can damage a perfectly healthy environment into one where it becomes difficult for living beings to survive. This also sets aside the much accepted belief, in the early seventies, that "solution to pollution is dilution". We now have to look beyond Bombay and its creeks to areas *e.g.* off Cochin, Visakhapatnam, Madras, where the discharge of domestic sewage and other

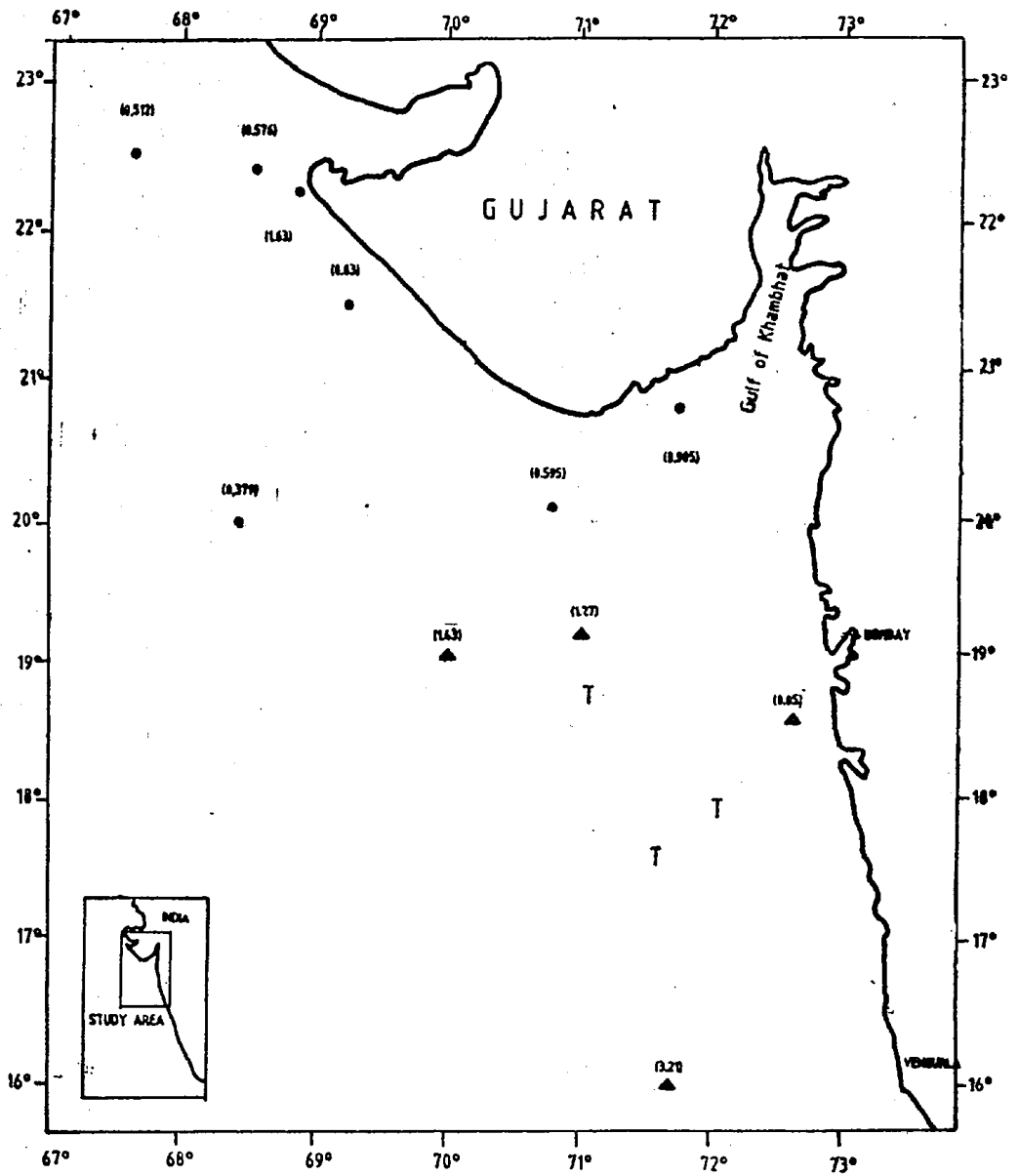


Fig. 1 † - DDT IN ZOOPLANKTON OF THE EASTERN ARABIAN SEA. CLOSED TRIANGLES ARE OBSERVATIONS IN 1978. CLOSED CIRCLES INDICATE RESULTS OF OBSERVATIONS IN 1985. T INDICATES PRESENCE OF ORGANOCHLORINE RESIDUES IN TRACE QUANTITIES.

effluents may be creating a situation where natural conditions such as community structure and health may be changed and take necessary steps to curb it.

Heavy Metals

Metal pollution in the seas or even estuaries is invisible and insidious and does not attract enough attention or comment, as compared to oil pollution, unless catastrophic event like the Minamata case or the Itai-Itai disease both in Japan, take place. These were caused by metal poisoning of mercury and cadmium respectively. In aquatic environments—metals can be termed as “*conservative pollutants*” which once added to the environment are there for ever and cannot be broken down to harmless substances by bacterial action as many organic pollutants are. Most of them are, however, perfectly natural substances occurring in seawater, though often in extremely low concentrations. They are leached or introduced into the aquatic systems as a result of the weathering of soils and rocks, from underwater volcanic activities, and from a variety of man-made sources, which involve mining, processing or use of metals or substances that contain metal contaminants. This is which changes the natural concentrations of metals in sea water resulting in a ten or even a hundred fold increase near the source of an effluent discharge. Although many metals are poisonous at quite low concentration, they are often vital as trace elements. Hence, while manganese, copper, iron, zinc etc. are considered essential micronutrients, mercury, cadmium and lead are not required for any important biological function by any organisms and are termed as non-essential elements.

Generally speaking, except at a few places, metal pollution in the sea is not and never was at dangerous levels, but the potential threat it offers is sufficient to merit a careful watch, in terms of monitoring programmes. Metals once introduced in the sea water, either naturally or as contaminants undergo various alternatives. Apart from dilution and dispersion there are biogeochemical processes which remove metals from the sea water, or in other words reduce the concentrations of the added metal in sea water. These are, precipitation, adsorption by suspended matter and absorption by organisms. It is the last process that includes removal by zooplankton ‘debris’ and other organisms which is of prime concern to man. This has led to much interest in determining the levels of heavy metals in a wide variety of commercially important marine fishes more as a food hygiene study. Fewer studies deal with the levels of heavy metals in other economically unsuitable species to determine and understand whether the high levels of metals reported in some species are due to the generally increased levels of the particular metal in the marine ecosystems or are a physiological peculiarity of that particular species. It is generally believed that for every metal there is one or more organisms which can bio-accumulate it.

Our efforts at the National Institute of Oceanography have been concentrated on establishing the baseline levels of several heavy metals, especially toxic metals like Hg, Cd, and Pb, in various segments of the marine environment around India, thus, giving us a good data pool in sea water and marine organisms. The ranges of concentrations of heavy metals in sea water as determined by several workers are presented in Table III. As is evident from the Table III a wide variations exists in

the ranges reported which have been assigned to, firstly the areas of sampling and secondly the sampling and analytical techniques employed by various workers. The ranges of dissolved heavy metal concentrations are in any case fairly high and so are the concentrations in particulate matter which have been attributed to river discharges (see Qasim and Sen Gupta, 1988 and Sen Gupta *et. al.*, 1984). Holeman (1968) has roughly given the amount of sediments added annually to the seas around India, by the rivers as 16×10^8 tonnes. Major portion of these additions settle at the confluences of the rivers with the sea. Most of the heavy metals can be expected to be transported through this route. This has been illustrated by our observations in the estuarine regions of Hooghly river. These observations were carried out in September, when the freshwater run-off and consequently suspended solids can be expected to be maximum. On analysing several heavy metals in suspended matter filtering large volume of water, from two stations, every three hours over two tidal cycles, at stations located in the final 125 km stretch of the river revealed that 5-9% of these suspended and particulate metals are precipitated in the estuarine region, 45-50% in the mouth region and about 40% would finally flow out to the Bay of Bengal. Similar observations on dissolved metals indicated that 85% settles in the estuarine and mouth region leaving only 15% to flow out to the Bay of Bengal. Some of the metals could be biologically active and harmful. Their effects on the environment can be anybody's guess.

It is this aspect which we investigated by analysing the metal concentrations in zooplankton, shell fishes, small and large fishes representing practically every level of the food chain. These levels are presented in Table IV. The tissue-wise break up of the concentrations is given in Table V. As is evident from Table IV the ranges of concentrations vary widely. Generally speaking the levels indicate normal environmental levels to be expected, barring a few cases which could be due to isolated instances of physiological peculiarities or even 'errors' due to several reasons. From the food hygiene point the concentrations are below the maximum permissible limits set by World Health Organisation for metals in fishing products for human consumption. Higher concentrations of metals (Table V) are mostly in those tissues which are not consumed as food. Metal to metal preferential assimilation can be observed with most of the metals being the highest in liver, kidney, gills etc. with the exception of Hg, which tends to accumulate more in muscles. Generally the indications are that most of these metals are assimilated by fishes in fat-soluble form. In our observations it was also noted that zooplankton showed high concentrations of practically all the metals except Hg. This element could not be detected in any of the zooplankton sample. These observations suggest the availability of these metals in the surface and sub-surface layers of the sea giving further evidence to an important source of their addition to the seas—the atmospheric transport. However, no evidence is seen of food chain magnification of these metals from zooplankton to higher fishes. However, acceptable correlation for certain metals was observed in different fish tissues with respect to their length and stages of maturity.

We have seen that no clear evidence of contamination exists as far as levels of heavy metals in marine organisms are concerned. The levels found, more or less, reflect the natural levels of concentrations with time. However in areas such as off

Bombay city and its environs like the Thane Creek and Mahim Bay the levels of heavy metals in organisms are quite high and do clearly indicate environmental degradation of these areas to the level of making some of the organisms unfit for human consumption (Ganesan *et. al.*, 1980).

The most interesting observations, though limited, come from sediment analysis. The limited data available is for Hg, Cd and Pb in nearshore sediments which do not show any definite pattern. Though Hg was found in very low concentration in the Indian nearshore sediments, some comparatively high concentrations were found off Bombay. Though of no environmental significance Cd and Pb show haphazard distribution with levels of non-detectability to 80.0 ppm and 35.0 ppm respectively with over 80% of the samples showing Cd and Pb below 1.0 ppm. This, however, needs further investigations which are underway at the National Institute of Oceanography.

Pesticides

Studies on pesticidal residues in our environment assumes great importance because of our dependence on agriculture, and also being a tropical country, on the control of many vector-borne diseases. It is this second control where the role of one of the most persistent and widely used pesticide DDT cannot be ignored in our country. DDT, since its inception and use during the second world war, has been applied extensively throughout the world. According to one report of W.H.O., DDT has been responsible for tremendous boost in agriculture as well as total eradication of, though momentary, vector-borne diseases.

It would be proper to mention here that innumerable types of pesticides, herbicides, fungicides etc. are extensively used in our country. These chemicals can broadly be classified into three categories which are commonly used. These are organochlorines, organophosphates and carbamates. Out of these the organochlorine pesticides like the DDT, BHC, Aldrin, Dieldrin, endrin, toxaphene etc. are called the persistent chemicals with half lives of years and perhaps even decades or centuries. Comparatively the other two groups of pesticides *i.e.* the organo-phosphorous, and carbamates have relatively short half lives and are easily bio-degraded to harmless substances and hence do not pose any serious environmental problems as compared to organochlorines.

The oceans are always the ultimate sink for all these chemicals used on land. It is estimated that as much as 25% of DDT compounds produced to date may have been transferred to the sea (NAS 1971). It has also been estimated that DDT compounds in the marine biota amounts to about 0.1% of its total production and yet this amount has produced a demonstrable impact upon the marine environment. Effects, such as reproductive failures in marine birds and fish, inhibition of photosynthetic activity etc. are a few examples apart from increased levels in marine food chain. With these continuing accumulations of persistent chlorinated hydrocarbons in the marine ecosystem, additional species may be threatened. Seeing these potential dangers many western nations have banned the use of DDT and many other related compounds in agriculture, industry and health programmes. We in India continue to use them more because of cost benefit than anything else.

Most of the reports of pesticide concentration in the environment are from inland sources *i.e.* in human beings, foodstuffs etc. and very few have dealt with the concentrations of these pesticides in the marine environment of India. Kureishy *et. al.* (1978) reported values of DDT and its isomers as total DDT (t-DDT) of 0.05 to 3.21 ppm wet weight in zooplankton from the north eastern Arabian Sea. Recent observations (Kannan and Sen Gupta, 1985) from the same area have shown values of 0.379 to 1.63 ppm wet weight in zooplankton (Fig. 1). Concentrations of t-DDT in the waters of the eastern Arabian Sea range from 0.06 to 0.16 ng/l while those in the air over the same area varied from 0.93 to 10.9 ng m⁻³ (Tanabe and Tatsukawa, 1980). These residues do suggest that the transfer of these compounds through atmosphere to the seas are significant enough to cause concern. The concentration factor of several orders of magnitude from sea water to zooplankton also suggests that the increase of DDT and related compounds in organisms higher up in the food chain can be a possible threat to human beings consuming them as food. Though it must be said that the lipophilic nature of these compounds make them increase in concentrations more on fat weight basis than the size of organisms. The studies, now on, will concentrate on analysing these persistent chemicals in all the segments of marine environment around India to give an overall situation as regards the pesticides. There is a general belief that though the use of DDT has been banned in the industrial countries, yet its total production and consumption has not gone down, rather it has increased. This has led to the hypothesis of a 'southward tilt' of pesticides which is under investigation now.

Oil

The vulnerability of Indian seas to increasing and possible oil discharges cannot be overemphasized. This is true specially for the Arabian Sea and the southern Bay of Bengal. Sen Gupta and Qasim (1985) and British Petroleum (1984) report the global marine transport of oil in 1983 was 1206 MT of which 513 MT or 42.5% was shipped from the gulf countries. Needless to say that most of this oil is transported across the Arabian Sea to the west and Far east along the two tanker routes with a very small percentage being shipped through the Suez Canal. The transport of oil plus the increasing offshore exploration and exploitation activities of the Oil and Natural Gas Commission of India makes the Northern Indian Ocean quite vulnerable to oil pollution.

The sources of oil entering the marine environment are both natural and man-made. It is the accidental and operational discharges *e.g.* tanker and oil well disasters, ballast discharges, bilge washings and land based discharges which assume great importance as far as the threat by oil based pollutants to the marine environment is concerned. Oil, once discharged in the marine environment undergoes various biochemical as well photochemical degradation, with light molecular weight hydrocarbons evaporating first and the oil film spreading along the water surface depending upon the sea conditions. The heavy molecular weight hydrocarbons, either get dissolved or being heavy start sinking collecting suspended matter in the process. This ultimately forms a chocolate "mousse" which settles to the bottom to be later brought

up by churning or by the prevalent current pattern to the surface or are washed ashore on the beaches. The effects of this oil leaked or discharged are many depending upon the size of the spill and area. The most visible effects take place in birds, the benthic and the intertidal fauna. The thin film of oil present at the surface could also be a deterrent to oxygen exchange across the air-sea interface, but on the other hand it also acts as solvents for a wide variety of organic pollutants.

In general discharged oil in sea exists as oil slicks, dissolved dispersed petroleum hydrocarbons, floating petroleum residues (tar balls) and tar on beaches. Observations on all these aspects have been on for quite a long time and very interesting results have come to light, Sen Gupta and Kureishy (1981) reported observations on oil slicks and other floating pollutants from data obtained from Japan Regional Oceanographic Data Centre. Out of 6689 observations, about 5582 or 83.5% of total showed positive signs of oil slicks or other floating pollutants in the Northern Indian Ocean. Floating tar observations too revealed a range of 0 to 6.0 mg/m² with a mean of 0.59 mg/m² in the Arabian Sea. The range of floating tar along the tanker route in the Southern Bay of Bengal was 0 to 69.75 mg/m² with a mean of 1.52 mg/m² indicating this area to be more polluted than those across the Arabian Sea. It was also observed that the occurrence of floating tar largely depends on the prevailing current pattern. Near absence of floating tar particles were noted during extensive observations made in June-September 1988 along the west going tanker route. This can be explained by the fact that during the period of study the surface currents on the Arabian Sea normally flow towards the Indian west coast. The details of various observations are given in Table VI.

The concentrations of dissolved and dispersed petroleum hydrocarbons in the upper 20 meters in the Arabian Sea are also given in Table VI. The ranges are quite uniform excepting some occasional high values. Seasonal variations could be observed which could be attributed to the varying tanker traffic and environmental conditions. However, the values did not change much from the year 1978 to 1984 though the transport of oil from the middle eastern countries has reduced appreciably. This leads us to believe that the existing "oil pollution" is not necessarily due to the amount of oil transported but depends largely on the tanker and other shipping activities like bilge and bunker washings.

The deposition of tarry lumps on the Indian beaches was first studied in 1975 when it was found that, specially, the beaches on the west coast were soiled with tar particles during the SW monsoon season. This is mainly because the onshore component of the alongshore current is strongest from April/May to Sept./Oct. Studies in 1975 and 1976 on several beaches of the west coast gave a range of 22 to 448 gm⁻² with peak value, on one occasion, of 1386 gm⁻². This deposition decreases to almost nil during reversal of the current pattern. The computed total deposit on beaches along the west coast of India are 1000 and 750 tonnes for 1975 and 1976 respectively (Dhargalkar *et. al.*, 1977).

An indication of the effect of oil exploration activities on the marine environment can be had from the concentrations of dissolved/dispersed hydrocarbons in the range of 2-46 µg/l in water and 4 to 32 µg/g dry weight in sediments in the near-

shore area of Bombay High region. Similarly, a near-catastrophic event took place in the Bombay Harbour region, where after a tanker fire accident the concentrations of dissolved/dispersed hydrocarbons ranged from 27-105 $\mu\text{g/l}$ at the surface and from 36 to 59 $\mu\text{g/l}$ at 5m. The concentrations in sediments increased from 1-26 $\mu\text{g/g}$ to 40-512 $\mu\text{g/g}$ after the accident. These observations prove the likely events and effect that these accidents might have on the Indian marine environment.

From the information so far available it can be said that there is no serious threat to the Indian marine environment as yet. This is more because of the nature and geographical location of the Northern Indian Ocean. The Northern Indian Ocean and its arms like the Arabian Sea, the Bay of Bengal including the Laccadive and the Andaman Sea are open seas. The impact of semi-diurnal tides associated with bi-annual reversal of the direction of monsoon winds and the resulting surface currents give this area enough flushings and water exchanges to dilute and disperse the incoming pollutant load. However, with increasing population and settlements along the coastline and industrialization, excessive loads are exerted on the coastal environment. We should remember that though we have the advantage of open seas, unlike the Baltic and the Mediterranean which had become heavily contaminated due to increasing inputs of land based pollutants from countries surrounding them until the time it was realised that the seas should not be considered 'dumping sites' for all sorts of chemicals and wastes, we should react in time and use this advantage of events that took place somewhat else, to keep our coastal waters and the seas clean.

REFERENCES

- Braganca, A and Sanzgiri, S. (1980). *Ind. J. Mar. Sci.* 9 : 283-286.
- British Petroleum, (1984). *BP Statistical Review of World Energy*, British Petroleum, London, 82 pp.
- Danielsson, L.G. (1980). *Mar. Chem.* 8 : 199-215.
- Dhargalkar, U.K., Kureishy, T.W., and Bhandare, M.U. (1977). *Mahasagar, Bull Natl Inst Oceanog.* 10 : 103-108.
- Ganesan, R., Shah, P.K. Turel, Z.R. and Haldar, B.C. (1980). Study of heavy metals (Cd, Hg and Se) in the environment around Bombay by radiochemical neutron activation analysis. *Transactions 4th International Conference on Nuclear Methods in Environment and Environmental Research*, Univ. Missouri, USA.
- Ghosh, B.B., Ray, P. and Gopalakrishnan, V. (1973). *J. Inland Fish Soc. Ind.* 5 : 82-101.
- Holeman, J.N. (1968). *Water Resources Research*, 4 : 787-797.
- Johnston, R., (1976). *Mechanisms and Problems of Marine Pollution in Relation to Commercial Fisheries*. In : "Marine Pollution, Ed. R. Johnston, Acad Press, pp. 3-155.
- Kannan, S.T. and Sen Gupta, R. (1985). *Mar. Poll. Bull.* (In press).
- Kureishy, T.W., George, M.D. and Sen Gupta, R. (1978). *Ind. J. Mar. Sci.*, 7 : 54-55.
- National Academy of Sciences, 1971 : *Chlorinated Hydrocarbons in the Marine Environment*.
- Qasim, S.Z. and Sen Gupta, R. (1982). *Marine Pollution Studies in India*. In "Water Pollution and Management Reviews, II 1982 Ed C.K. Varshney, South Asian Publishers, New Delhi, 139-159.
- Qasim, S.Z. and Kureishy, T.W. (1986). *Proceedings INSA* (In Press).
- Sabnis, M.M. (1984). Ph. D. Thesis, *University of Bombay*.
- Sanzgiri, S., Sen Gupta, R. and Singbal, S.Y.S. (1979). *Ind. Mar. Sci.*, 8 : 252-254.

- Sanzgiri, S. and Moraes, C. (1979). *Ind. J. Mar. Sci.*, **8** : 254-256.
 Sen Gupta, R. and Sankaranarayanan, U.N. (1975). *Bull. Natl. Inst. Oceanogr.*, **7** : 73-78.
 Sen Gupta, R., Singbal, S.Y.S. and Sanzgiri, S. (1978). *Ind. J. Mar. Sci.*, **7** : 295-299.
 Sen Gupta, R. and Kureishy, T.W. (1981). *Mar. Poll. Bull.*, **12** : 295-301.
 Sen Gupta, R., Naik, S. and Varadachari, V.V.R. (1984). *Ectotoxicology, SCOPE*, (In Press).
 Sen Gupta, R. and Qasim, S.Z. (1985). *Mahasagar, Bull. Natl. Inst. Oceanogr.*, **18** : 79-90.
 Singbal, S.Y.S., Sanzgiri, S. and Sen Gupta, R. (1978). *Ind. J. Mar. Sci.*, **7** : 124-126.
 Tanabe, S. and Tatsukawa, R. (1980). *J. Oceanogr. Soc. Jap.*, **36** : 217-226.
 Topping, G. (1969). *J. Mar. Res.*, **27** : 318-326.

TABLE I

**Population and Related Data and some Estimates of Pollutants Entering the
Sea Around India (as of 1984)**

Pollution	720 million
Coastal population (25% of total)	180 million
Area of the Country	$3.276 \times 10^6 \text{ km}^2$
Agricultural area	$1.65 \times 10^6 \text{ km}^2$
Exclusive economic zone	$2.015 \times 10^6 \text{ km}^2$
River runoff (annual mean)	$1,645 \text{ km}^3$
Rainfall per year (on land)	$4.0 \times 10^{12} \text{ m}^3$
Rainfall per year (on Bay of Bengal)	$6.5 \times 10^{12} \text{ m}^3$
Rainfall per year (on Arabian Sea)	$6.1 \times 10^{12} \text{ m}^3$
Domestic sewage added to the sea by coastal population per year (@ 60.1 per head/day)	$3.9 \times 10^9 \text{ m}^3$
Industrial effluents added to the sea by coastal industries per year	$0.39 \times 10^9 \text{ m}^3$
Sewage and effluents added by the rivers to the sea per year	$50 \times 10^6 \text{ m}^3$
Solid waste and garbage generated by Coastal population per year (@ 0.5 kg per head/day)	$33 \times 10^6 \text{ tonnes}$
Fertiliser used per year (@ 30.5 kg/ha yr ⁻¹)	$5 \times 10^6 \text{ tonnes}$
Pesticides used per year (@ 336 g/ha. yr ⁻¹)	55,000 tonnes
Synthetic detergents used per year	1,2500 tonnes
Oil transported across the Arabian sea in 1983	$513 \times 10^6 \text{ tonnes}$
Oil transported to Western Hemisphere in 1983	$291 \times 10^6 \text{ tonnes}$
Oil transported to Far East and Japan in 1983	$222 \times 10^6 \text{ tonnes}$
Tar deposition on beaches along the West Coast of India per year	750—1000 tonnes

TABLE II
Pollutants discharged to Mahim Bay (Bombay) every year (in tonnes)

Dissolved solids	92,619
Chlorides	37,495
BOD	16,480
Suspended solids	15,649
Sulphates	4,791
Nitrogen	2,236
Phosphorus	383
Iron	162
Manganese	32
Zinc	16
Copper	7
Nickel	5
Cobalt	2
Lead	0.7

TABLE IV

Ranges of Concentration of a few essential and non essential Heavy Metals (PPM Wet Weight) in Zooplankton, Crustaceans, Bivalve & Muscles of certain Fishes from the Northern Indian Ocean

Fish	Essential Heavy Metals							Non Essential Heavy Metals				
	Cu	Fe	Mn	Zn	Ni	Co	Pb	Cd	Hg			
Zooplankton	2.0—5.0	35.0—94.0	3.0—7.0	8.0—31.0	0.2—3.0	ND—4.0	1.0—12.6	0.02—5.99	ND			
Prawns (6 Spp)	3.5—24.0	—	—	—	—	—	1.0	0.2—2.5	ND—0.17			
Crabs	0.7—13.5	—	—	—	—	—	<1.0—7.88	0.61—1.12	0.004—0.01			
Clams	—	—	—	—	—	—	1.28	1.66	0.06			
Oysters	45.0	—	—	—	—	—	<1.0	1.36	0.02			
Mussels	—	—	—	—	—	—	1.31	1.38	0.09			
Flying Fish	0.1—0.7	4.0—62.0	ND—3.7	4.0—21.0	ND—0.9	0.2—1.3	1.08—5.76	ND—0.65	ND—0.07			
Silver Bellies	1.0—1.6	—	—	—	—	—	<1—3.21	0.58—2.11	0.001—0.01			
Malabar Anchovies	4.4	—	—	—	—	—	<1	0.7	0.01			
Sardines (2 Spp)	0.03	8.0—10.0	0.2	4.5—6.3	—	—	<1	ND—0.62	ND—0.01			
Mackarel (2 Spp)	1.0—1.3	12.0	0.01	6.0	ND	0.7—1.1	<1	0.22—1.62	0.01—0.02			
Jew Fish (2 Spp)	ND—0.8	6.0—8.0	0.3—10.0	4.0—4.8	ND	1.8	<1	0.19—0.42	0.006—0.01			
Perch (Spp)	0.2—0.7	6.0—29.0	ND—0.1	3.4—6.1	0.3—0.5	ND	<1	ND—1.47	0.007—0.1			
Pilot Fish	0.1—4.9	—	—	—	—	—	<1—2.95	ND—0.83	ND—0.02			
Scianid (2 Spp)	0.1—0.3	—	—	—	—	—	<1	0.86—1.36	ND—0.02			
Sole	—	—	—	—	—	—	<1	0.35	0.01			
Pomfret	—	—	—	—	—	—	<1	0.73	0.01			
Cat Fish	—	—	—	—	—	—	1.02	0.92	0.06			
Trevally (2 Spp)	ND—0.7	5.0—11.0	0.1—9.0	2.0—5.0	ND—0.6	ND—1.2	<1	ND—0.62	0.018—0.08			
Grunter	0.36	—	—	—	—	—	2.7	ND	0.24			
Talang	0.4	—	—	—	—	—	<1	ND	0.36			

Tuna (4 Spp)	0.3-3.0	7.0-164.0	0.1-7.5	4.0-12.0	ND-4.0	ND-3.2	<1-3.3	ND-2.00	0.004-0.22
Dolphin Fish	0.2-1.7	13.0-39.0	ND-3.1	5.0-9.0	0.1-1.2	ND-1.9	<1-2.95	ND-0.95	0.01-0.14
Seer Fish	0.4	-	-	-	-	-	<1-1.5	0.25-0.66	0.09-0.11
Borracuda	0.1-0.5	4.0-17.0	0.2-3.1	3.3-5.8	0.1-0.3	0.6-1.9	<1	ND-0.28	0.06-0.2
Sea Pike	-	-	-	-	-	-	1.46	ND	0.11
Sharks (4 Spp)	0.14-1.1	10.0-57.0	ND-2.0	4.5-12.0	ND-0.3	ND-3.8	<1-6.02	ND-0.81	0.02-0.21

ND-Not Detectable.

TABLE V
Ranges and average concentrations of a few toxic heavy metals (ppm wet weight) in different body parts of fishes from the Northern Indian Ocean

Body parts	Mercury		Cadmium		Lead	
	Range	Average	Range	Average	Range	Average
Muscle	ND—0.36	0.07	ND—3.24	0.59	ND—3.43	1.11
Liver	ND—0.04	0.01	1.2—87.3	20.18	1—17.62	3.8
Gill	ND—0.08	0.016	ND—0.76	0.42	1—7.0	3.14
Heart	ND—0.08	0.02	ND—1.91	0.54	1—3.4	1.36
Kidney	ND—0.04	0.015	0.38—36.69	9.02	1—69.46	8.61
Conads	ND—0.03	0.015	ND—8.06	1.25	1—4.76	1.36

ND—non detectable

TABLE VI
Dissolved/Dispersed Hydrocarbons, Particulate Petroleum Residues
(Tar Balls) in and Transport of Oil Across the Arbian Sea

Months/year	Dissolved/Dispersed Hydrocarbons ($\mu\text{g.l}^{-1}$)			Tar Balls (mg. m^{-2})
March 1978	0.6—22.9	0.9—18.1	25—28	0.02—0.32
June 1978	—	—	—	1.26—3.46
December 1978	21.5—42.8	16.8—42.5	28.6—37.5	0—0.54
May 1979	—	—	—	—
December 1979	18.6—41.6	16.9—34.15	10.4—24.9	—
February 1980	6.4— 9.0	3.1— 6.3	2.4— 4.5	0—0.53
October 1980	47—230	77—210	—	—
November 1980	2.6—55.6	1.9—36.0	—	—
January 1981	4.0— 9.5	ND— 2.5	—	—
March 1981	200—305	130—277	—	0.30—112.2
February 1982	—	—	—	0—0.06
January 1983	9.7—24.2	6.7—13.2	2.2—7.2	0—0.06
July 1983*	3.0—8.9	ND—1.2	ND—1.0	0—PI
September 1983*	7.4—16.2	3.4—8.5	ND—1.2	0—PI
October 1983*	5.7—10.6	2.1—5.4	ND—1.1	0—PI
November 1983*	5.1—12.4	1.4—6.1	ND—1.6	—
May 1984	22.9—114.6	18.6—62.2	18.9—72.0	0—0.06

Transport of Oil

Year	Volume (MT)
1977	1024.4
1978	974.9
1979	1009.6
1980	869.3
1981	725.4
1982	578.7
1983	512.9

*Data are from the west-going tanker route. Rest are from the east-going tanker route.
ND—Non detectable; PI—Presence Indicated.