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Pollution of the seas around India

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Abstract. The state of marine pollution along the 7000 km long coastline and $2\cdot015 \times 10^6$ km^2 exclusive economic zone of India is summarized. The coastal water receives $4\cdot1$ km^3 of domestic sewage and $0\cdot41$ km^3 of industrial wastes. Nearly 447 million tonnes of oil and its products are transported through the Arabian Sea and Bay of Bengal with the result that some of our coastal areas particularly adjoining the large cities are getting polluted. Increased eutrophication and decrease in dissolved oxygen associated with the generation of toxic hydrogen sulphide have been observed at several places. Heavy metal concentrations are largely within the acceptable limits in water and in biota excepting in a few areas. Organochlorine and pesticides residues have often been found to be high in zooplankton and in the sediments near the confluence of the river and the sea, indicating their land origin. Oil pollution is a chronic problem in the northern Indian Ocean. Several of the endangered ecosystems have now been offered protection by declaring them as marine parks. It is recommended that to maintain coastal waters clean, wise and judicious use of the ocean must form an integral part of our planning.

Keywords. Pollution; sewage; metals; pesticides; oil; estuaries; coastal environment.

1. Introduction

A decade of marine pollution investigations has been completed since the commissioning of the first oceanographic research vessel *Gaveshani* in February 1976. The ocean research vessel *Sagar Kanya*, commissioned in June 1983, has since generated a wealth of information which can be accepted as the state of art documentation on the health of the seas around India. These pioneering efforts have given thrust to marine pollution research in India and through the concerted efforts of the Department of Ocean Development and the National Institute of Oceanography, the programme of work in this discipline is presently well organised. The need for a sustained activity has been clearly spelt-out (Qasim and Sen Gupta 1983; UNEP 1986).

2. Sources of pollution

Johnston (1976) has characterised 3 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 in the second; and plastics, radionuclides and pesticides in the third.

Estimates of the pollutants entering the seas around India made in 1986 are given in table 1. It is clear from this table that a considerable amount of polluting

Table 1. Human pollution and related data together with estimates of pollutants entering the seas around India (as in 1986).

Population	750 million
Coastal population (25% of total)	188 million
Area of the country	$3{\cdot}276 \times 10^6$ km^2
Agricultural area	$1{\cdot}65 \times 10^6$ km^2
Exclusive economic zone	$2{\cdot}015 \times 10^6$ km^2
River runoff (annual mean)	1645 km^3
Rainfall per year (on land)	$4{\cdot}0 \times 10^{12}$ m^3
Rainfall per year (on Bay of Bengal)	$6{\cdot}5 \times 10^{12}$ m^3
Rainfall per year (on Arabian sea)	$6{\cdot}1 \times 10^{12}$ m^3
Domestic sewage added to the sea by coastal population per year (60 l per head/day)	$4{\cdot}1 \times 10^9$ m^3
Industrial effluents added to the sea by coastal industries per year	$0{\cdot}41 \times 10^9$ m^3
Sewage and effluents added by the rivers to the sea per year	50×10^6 m^3
Solid waste and garbage generated by coastal population per year (0·5 kg per head/day)	33×10^6 tonnes
Fertiliser used per year (30·5 kg/ha.yr^{-1})	5×10^6 tonnes
Pesticides used per year (336 g/ha.yr^{-1})	55000 tonnes
Synthetic detergents used per year	125000 tonnes

substances enter the Indian seas annually. To these if natural pollution species of atmospheric and weathering origins are added, it is obvious that these waters would need constant attention of marine scientists. In this communication we have discussed the extent of concentration of different categories of pollutants and their influence on the seas around India.

2.1 *Domestic sewage*

Domestic sewage, in small quantities, is known to fertilise the sea and increases the marine productivity. However, over-fertilisation creates stress leading to eutrophication. In the Arabian Sea where, low concentrations of oxygen naturally occur at intermediate depths, the additions of large volumes of sewage alter the oxygen balance in the surface and sub-surface waters thereby jeopardising the survival of living organisms. A recent study (Naqvi 1987) has indicated that the turnover time of the low-oxygenated and denitrified water is limited to only 4 years. This short renewal time of intermediate waters and the short-term variability of the denitrification intensity suggest that the oxygen poor layer of the northern Indian ocean is an unstable time-variable feature which may react quickly to any future climatic and/or environmental perturbations. Hence, a serious concern is expressed that a slight increase in the organic carbon flux due to pollution, and/or a climatic change could create a very significant impact on these intermediate waters turning them completely anoxic.

The consequences of the discharges of sewage and effluents are not very perceptible all along the Indian coast. However, in the nearshore areas of a few metropolitan cities crowded with large industrial complexes, the effects are indeed becoming very perceptible. Sen Gupta and Sankaranarayanan (1975) observed an increase of about 40% (0·82–1·13 μ mol l^{-1}) of phosphate-phosphorous concentrations during 1959–1974 in the nearshore waters of Bombay. More recent observations reveal a concentration of approximately 2 μ mol l^{-1} (Zingde 1985). Dissolved oxygen concentrations also showed a negative trend from 4·71 ml/l in 1959 to near zero in 1983 (Parulekar *et al* 1985). Higher values of phosphate-phosphorous were observed in the nearshore waters of Madras, as compared to the earlier values (Sen Gupta R, unpublished results). Sabnis (1984) estimated 365 million tonnes (MT) as a total volume of all discharges coming from the Bombay city alone every year. A similar estimate of about 396 MT was given by Ghosh *et al* (1973) from the environs of Calcutta city. These figures give an idea of the total volume of domestic sewage, industrial effluents and other wastes, being discharged into the coastal waters of India.

The Mahim bay in the city of Bombay is one more example of heavy contamination. This bay occupies an area of 64 km^2 and is influenced by semi-diurnal tides with a maximum range of 3 m. Sabnis (1984) has given the figures of the annual discharges to this bay which are presented in table 2. The bay receives 64 MT of domestic sewage annually apart from the other types of wastes which are now partially treated. H_2S-S concentrations in this bay range from 1·5–98·4 μ mol l^{-1} depending on the state of the tides. Thus an area, which once was a healthy ecosystem with good fisheries, oyster beds, fringing mangroves and inviting the migratory birds has become one of the most polluted regions in the country. This sets aside the much accepted belief held in the early seventies that 'solution to pollution is dilution'. The waters off Cochin, Visakhapatnam and Madras receiving discharges of domestic sewage and other effluents are also gradually facing a situation similar to Mahim bay. Evidently, appropriate actions to restrict the sources of pollution are therefore needed.

2.2 *Heavy metals*

Metal pollution generally goes unnoticed until catastrophic events like the *Minamata* or the *Itai-Itai* diseases occur. These were caused by mercury and cadmium poisoning respectively in Japan. In aquatic environments, metals have been termed as conservative pollutants because once added to the environment, they prevail for

Table 2. Pollutants discharged into the 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

ever. These metals cannot be broken down to harmless substances by bacterial action. Most of the metals are, however, present as naturally occurring substances in extremely low concentrations. They are leached or introduced into the aquatic systems as a result of weathering of soils and volcanic rocks and as a result of human activities involving mining and metal industry. These processes and activities change the natural concentrations of metals in the sea water resulting in 10- or even 100-fold increase near the point of an effluent discharge. While manganese, copper, iron and zinc are considered essential micronutrients, mercury, cadmium and lead are not required for any important biological function by organisms and are deemed as non-essential elements.

Metal pollution in the seas around India has not yet reached dangerous levels. But the potential threat it poses is serious enough to merit dependable and appropriate monitoring programmes. Metals introduced in the sea water as contaminants undergo various alterations. Apart from dilution and dispersion, the biogeochemical processes remove metals from the sea water or reduce their concentrations in the sea water. These are precipitation, adsorption on to suspended matter and absorption by the organisms. It is the last process which is of prime concern to man and has rightly created much interest in determining the levels of heavy metals in a wide variety of commercially important marine fishes. It is generally believed that for every metal there is one or more organisms which can bio-accumulate it. Presently, therefore, efforts are being made to identify such organisms which might have potential to emerge as pollution indicators or the survival organisms as they are called.

Efforts are also being made on establishing the baseline levels of several heavy metals, especially those which are toxic like Hg, Cd and Pb in various areas of the marine environment around India. The ranges of concentrations of heavy metals in the sea water, as determined by several workers are presented in table 3. As is evident from table 3, a wide variation exists in the ranges reported and this has been assigned to, firstly the area of sampling and secondly the analytical techniques employed by various workers. The ranges of dissolved heavy metal concentrations have been attributed to river discharges (Qasim and Sen Gupta 1983; Sen Gupta and Qasim 1985a). Holeman (1968) has roughly given the amount of sediments added annually to the seas around India by the rivers as 16×10^8 tonnes. A major portion of these additions settles 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 the river Ganga. These observations were made in September, when because of monsoon rains, the fresh-water runoff and consequently the suspended solids are expected to be maximum. Analysis of several heavy metals in the suspended matter by filtering large volumes of water every 3 h, over two tidal cycles, at several stations located in the last 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 showed that 85% get into the estuaries and at the mouth of the rivers, and the remaining 15% flow out into the Bay of Bengal (NIO 1986).

An analysis of the metal concentrations in zooplankton, shell fish, small and large fishes representing different levels of the food chain, is given in table 4. The tissue-wise break up of the concentrations is given in table 5. As is evident from the tables, the ranges in concentrations vary widely. Higher concentrations of metals (table 5)

Table 3. Ranges of dissolved heavy metal concentrations (μg/l) in the Indian Ocean determined by various workers.

Source	Cu	Cd	Fe	Mn	Zn	Pb	Ni	Co	Hg(ng/l)
Topping (1969)	0·5–49·1	—	0·1–61·8	0·1–4·6	3·9–19·5	—	—	—	—
Chester and Stoner (1974)									
Surface only	0·2–1·2	0·02–0·14	0·5–3·1	0·07–0·37	0·3–3·0	—	0·3–2·6	—	—
Sen Gupta *et al* (1978)	1·7–7·9	—	7·2–66·9	—	0·5–42·4	—	0–11·5	0–6·6	—
Singbal *et al* (1978)	—	—	—	—	—	—	—	—	13–187
Sanzgiri and Moraes (1979)	1·9–19·9	—	8·5–96	1·8–80	1·2–29·7	—	0–16·3	0–6·7	—
Danielsson (1980)	0·08–0·48	0·01–0·16	0·15–10	—	0·6–13·8	0·02–0·18	0·18–0·95	0–0·02	—
Sanzgiri *et al* (1979)	—	—	—	—	—	—	—	—	0–24
Braganca and Sanzgiri (1980)	22–37·2	—	6·2–131·5	1·8–40·8	2·4–20	—	0–12·2	0–7·9	—
Sanzgiri and Braganca (1981)	1–5	0·15–1·9	2–21·7	1·5–24·7	1·2–12·8	0·25–7·5	0–1	0–1	—
Fowler *et al* (1984)	0·22–1·2	0·005–0·1	—	—	0·002–0·91	0·05–0·12	—	—	4–3

Table 4. Ranges of concentration of some essential and non essential heavy metals (ppm wet weight) in zooplankton, crustaceans, bivalves and in the muscles of certain fishes from the northern Indian Ocean.

	Essential heavy metals						Non essential heavy metals		
Fish	Cu	Fe	Mn	Zn	Ni	Co	Pb	Cd	Mg
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	ND-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	—	0·7-1·1	1	ND-0·62	ND-0·01
Mackerel (2 spp)	1·0-1·3	12·0	0·01	8·0	ND	1·8	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	0·7-1·1	1-1·14	0·19-0·42	0·006-0·01
Perch (3 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
Sciaenid (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
Barracuda	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.
Source: Kureishy (1985)

Table 5. Ranges and average concentrations of some toxic heavy metals (ppm wet weight) in different body parts of fishes from the northern Indian Ocean.

	Mercury		Cadmium		Lead	
Body parts	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–0·03	0·016	ND–0·76	0·42	1–7·0	3·14
Heart	ND–0·08	0·026	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
Gonads	ND–0·03	0·015	ND–8·06	1·25	1–4·76	1·36

ND, non detectable.
Source: Kureishy (1985).

are recorded mostly in those tissues which are not normally consumed as food. The concentrations of most of the metals are high in the liver, kidneys, gills and other organs, with the exception of Hg, which tends to accumulate more in the muscles. Generally the indications are that most of these metals get assimilated by fishes in fat soluble forms. We have also noted that zooplankton generally have high concentrations of practically all the metals except Hg.

Surface and subsurface layers of the sea provide further evidence that one of the mechanisms of the addition of metals to the sea is atmospheric transport. However, no evidence is available of the transfer of these metals from zooplankton to fish. A correlation between certain metals and the size of the fish and their stages of maturity was found in some species (Kureishy 1985).

The levels of heavy metals found in several marine organisms, more or less, reflect the natural levels of their concentrations occurring in the sea. On the other hand, in areas such as the coastal waters of the Bombay city, particularly the Thana creek and Mahim bay, the levels of heavy metals in organisms are quite high and this clearly indicates considerable environmental degradation of these areas to the level of making some of the animals taken as human food unfit for consumption (Ganesan *et al* 1980).

Some observations made on the heavy metals from the analysis of the sediments can be summarised as follows: Limited data available for Hg, Cd and Pb in the nearshore sediments, do not show any definite pattern. Though mercury was found in very low concentrations in the nearshore sediments, there were some high values recorded off Bombay. Cadmium and lead show random distribution from non-detectable levels to 80 ppm and 350 ppm respectively. More than 80% of the samples showed Cd and Pb below 1 ppm.

2.3 *Pesticides*

It is estimated that about 25% of the DDT compounds produced to date might have been already transferred to the sea. It has also been estimated that DDT compounds in the marine biota amount to about 0·1% of its total use. Even such small amounts have produced a significant impact. Effects, such as reproductive failures in sea birds and fish, inhibition of photosynthetic activity among algae are a few examples apart from their transfer into the marine food chain.

Most of the reports on pesticide concentrations in human being as well as in foodstuffs in India are related to terrestrial environment. Kureishy *et al* (1978) reported values of DDT and its isomers as total DDT (t-DDT) of 0·05–3·21 ppm wet weight in zooplankton from the north-eastern Arabian Sea. Recent observations (Kannan and Sen Gupta 1987) from the same area have shown values of 0·379–1·63 ppm wet weight in zooplankton (figure 1). Concentrations of t-DDT in the waters of the eastern Arabian Sea ranged from 0·06–0·16 ng/l while those in the air over the same area varied from 0·93–10·9 ng m^{-3} (Tanabe and Tatsukawa 1980). These residual levels do suggest that the transfer of the compounds through

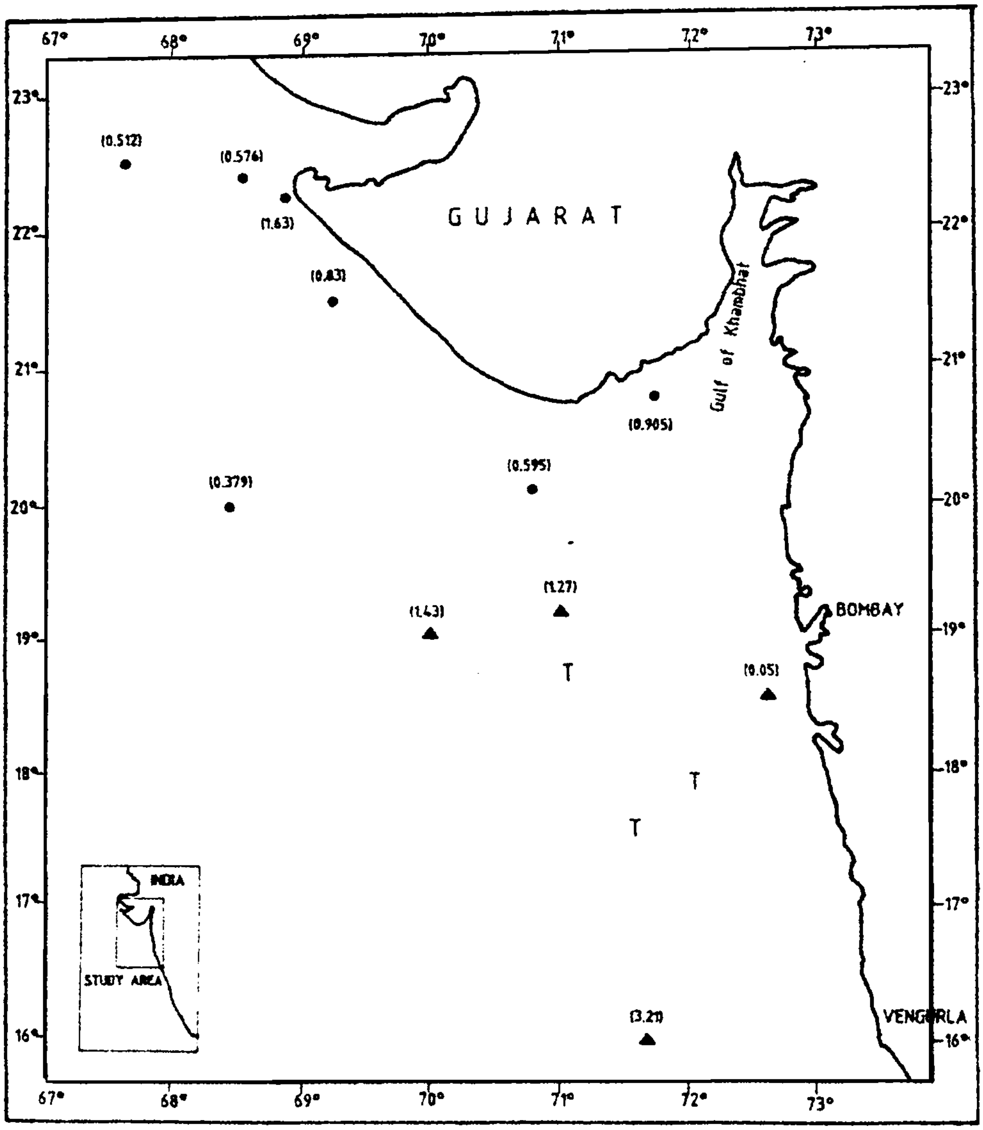

Figure 1. DDT in zooplankton of the eastern Arabian Sea. (▲) Observations made in 1978; (●) Results of observations in 1985. T indicates the presence of organochlorine pesticides residues in trace quantities.

atmosphere to the seas is notable enough to cause concern. The high concentrations of DDT in zooplankton pose a potential threat of their being transferred to higher organisms through food chain. This aspect is receiving attention by workers engaged in environmental monitoring.

A recent study (Sarkar and Sen Gupta 1988) of pesticides residues in the sediments along the east coast of India indicated that apart from DDT and its isomers, residues of gamma-BHC, Aldrine and Dieldrine were recorded from a number of places. Their individual concentrations were, in some areas, higher than t-DDT (table 6). These concentration values are high mainly at the river mouths (figure 2), indicating that these pesticides are of land origin.

2.4 *Oil*

Sen Gupta and Qasim (1985b) and British Petroleum (1986) reported that the global-marine transport of oil in 1986 was 1264 MT; of which, 447 MT or 35·4% of the total was shipped from the Gulf countries. About two-thirds of this oil is transported across the Arabian Sea to the west and far east along the two tanker routes. The total recorded incidence of accidental oil spills in the Indian Ocean, north of the equator, is 15 tanker disasters and 3 blow-outs from 1970–1982.

The problem of oil entering the marine environment is largely man-made. Oil, once discharged in the marine environment undergoes various biochemical as well as photochemical degradation. Light, volatile fractions evaporate first as the oil film spreads along the water surface and the heavier fractions either get dissolved or start sinking. During sinking, these fractions collect a lot of suspended matter and ultimately settle to the bottom to be later brought up as tar. This tar is subsequently washed ashore on beaches. The effects of discharged oil on the environment are many, depending upon the size of the spill and the area. The most visible effect is on the birds and on the benthic and intertidal fauna. The thin film of oil present at the surface could inhibit the oxygen exchange occurring across the air-sea interface. It can also act as solvent for a wide variety of organic pollutants.

Sen Gupta and Kureishy (1981) reported observations on the oil slicks and other floating pollutants based on the data obtained from the Japan National Oceanographic Data Centre. Out of 6689 observations, about 5582 or 83·5% of the total, showed positive signs of oil slicks or other floating pollutants in the northern Indian Ocean. Figure 3 shows recorded observations made on oil slicks and other floating pollutants over the entire Indian Ocean up to 40°S latitude. The data have been divided in 5° squares. The lower numbers in these squares indicate the occasions when oil slicks were present while those at the top show number of occasions when oil slicks were absent. A close look at the illustrations will indicate that the oil slicks occur very frequently along the tanker routes, while south of the equator there is less oil pollution in the Indian Ocean. Observations on floating tar too revealed a range of 0–6 mg/m^2 with a mean of 0·59 mg/m^2 in the Arabian Sea. The range of the floating tar along the tanker route in the southern Bay of Bengal was 0–69·75 mg/m^2 with a mean of 1·52 mg/m^2 indicating that this area was more polluted than that of the Arabian Sea. It was also observed that the occurrence of floating tar largely depended on the prevailing current patterns, being absent from June–September as the surface currents in the Arabian Sea happened to be towards

Table 6. Organochlorine pesticides residues in the sediments of the east coast of India ($\mu g/g$) wet weight.

Lat.°N	Long.°E	Depth (m)	-BHC	Aldrine	O-P′-DDE	P-P′-DDE	Dieldrine	O-P′-ODD	O-P-DDT	P-P′-DDD	P-P-DDT	Total DDT
22°11·2′	88°9·8′	8	0·046	0·315	0·060	0·021	0·046	ND	0·019	ND	0·049	0·149
22°0·4′	88°4·2′	12	0·051	0·456	0·090	0·022	0·513	ND	ND	0·30	0·066	0·478
20°42·1′	88°1·0′	13	0·007	0·059	0·034	0·007	ND	0·352	ND	0·012	0·010	0·415
20°13·8′	88°25·2′	50	0·013	0·044	0·21	0·013	ND	ND	ND	ND	ND	0·223
21°5·7′	88°58·5′	31	0·020	0·089	0·067	0·013	ND	ND	ND	ND	ND	0·080
20°18·1′	87°4·6′	43	0·015	0·059	0·018	ND	ND	ND	ND	ND	ND	0·018
19°14·8′	85°38·8′	65	0·093	0·065	0·081	0·044	0·058	ND	ND	ND	ND	0·125
19°15·1′	85°31·8′	50	0·045	0·056	0·031	0·024	ND	0·059	ND	ND	ND	0·114
19°15·0′	85°25·4′	45	0·053	0·092	ND	0·046	ND	ND	ND	ND	ND	0·046
19°15·0′	85°25·6′	35	0·079	ND	0·051	ND	0·098	0·042	ND	ND	ND	0·093
19°14·3′	85°18·9′	100	0·208	0·150	0·110	0·083	0·202	ND	0·038	ND	ND	0·231
19°15·3′	85°12·9′	85	0·052	0·040	0·042	0·047	0·154	ND	ND	ND	ND	0·089
19°15·5′	85°8·2′	90	0·056	0·072	ND	0·053	ND	ND	ND	ND	ND	0·053
19°13·8′	85°2·9′	95	0·044	0·051	0·058	0·057	0·177	ND	ND	ND	ND	0·115
19°13·8′	85°59·6′	71	0·104	0·177	0·065	0·068	ND	ND	ND	ND	ND	0·133
17°00·0′	85°00′	75	0·120	0·102	0·119	0·011	0·169	ND	ND	ND	ND	0·130
16°50·2′	82°43·8′	45	0·007	0·028	0·042	ND	ND	ND	ND	ND	ND	0·042
16°26·0′	82°31·0′	40	ND	ND	ND·	ND	ND	ND	ND	ND	ND	ND
16°11·0′	81°47·5′	55	0·080	ND*	0·056	ND	ND	ND	ND	ND	0·069	0·056
15°56·5′	81°19·6′	50	0·016	0·107	0·034	ND	ND	ND	ND	ND	ND	0·034
15°39·5′	81°00·0′	48	0·005	0·080	0·023	ND	ND	ND	ND	ND	ND	0·023
15°22·8′	80°33·1′	52	0·016	0·371	0·130	0·015	ND	ND	ND	ND	0·016	0·211
15°0·3′	80°16·7′	52	0·158	ND	0·105	0·018	ND	ND	ND	0·030	ND	0·183
15°0·0′	81°00·0′	80	0·033	0·120	0·076	0·084	0·271	ND	0·029	ND	ND	0·189
13°0·0′	82°0·0′	60	0·030	0·019	0·023	ND	ND	ND	0·018	ND	ND	0·041
13°0·0′	81°0·0′	30	0·026	0·033	ND	ND	ND	ND	0·030	ND	ND	0·030
13°0·0′	80°40′	35	0·034	0·033	ND	ND	ND	ND	ND	ND	ND	ND
13°0·0′	80°25′	45	0·043	ND	0·055	ND	ND	ND	ND	ND	0·133	0·188
12°0·0′	80°56′	19	0·017	0·527	0·103	0·34	ND	ND	ND	0·080	0·197	0·780

ND, Not Detectable.

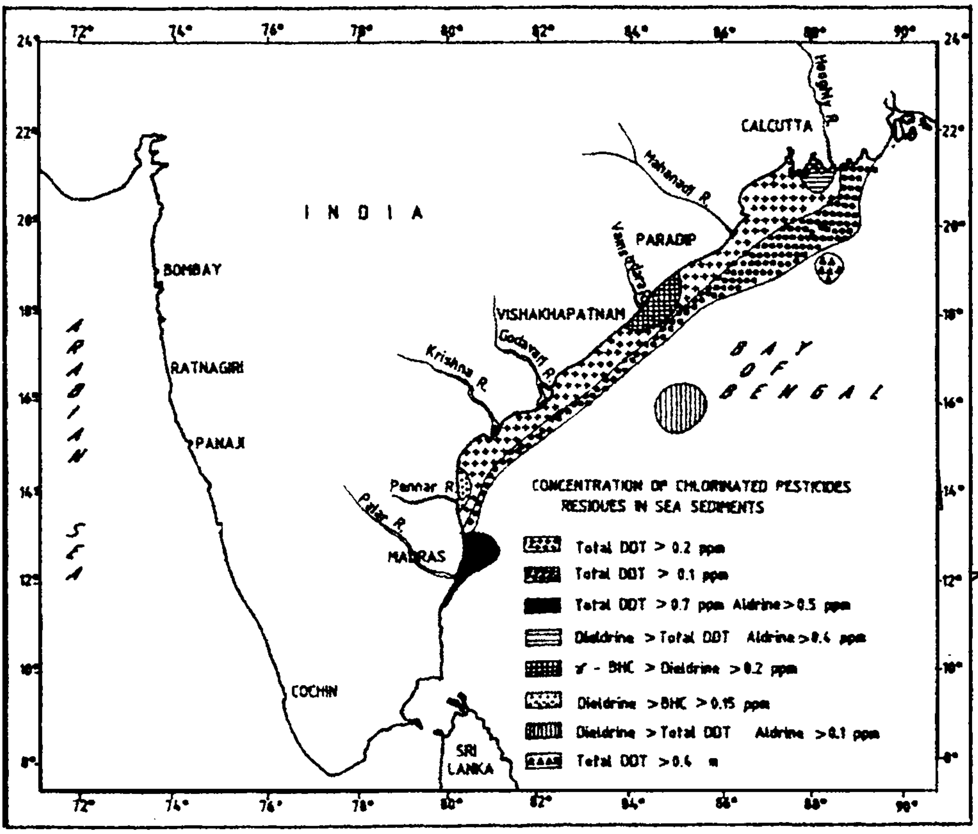

Figure 2. Concentrations of chlorinated pesticides residues in the sediments along the east coast of India.

the Indian coast. The tar particles have a residence time of 30–45 days (Sen Gupta and Qasim 1985b), before they start sinking towards the bottom.

The deposition of tarry lumps on the Indian beaches was first studied in 1975 when it was found that the beaches on the west coast in particular were having a high deposition of tar balls during the south-west monsoon season. This is mainly because the onshore component of the sea currents is strongest from April/May to September/October. Studies in 1975 and 1976 on several beaches of the west coast gave a range of 22–448 g m^{-2} with peak values, on one occasion of 1386 g m^{-2}. As the current pattern reverses, this tar deposition almost stops completely from November–March. The computed total deposit on the beaches along the west coast of India are 1000–750 tonnes for 1975 and 1976 respectively (Dhargalkar *et al* 1977). The concentrations of dissolved and dispersed hydrocarbons in the upper 20 metres are quite uniform in the northern Indian Ocean excepting on a few occasions. These largely depended on the tanker traffic as is evident from table 7.

Oil exploration activities off the Bombay High region are responsible for increased concentrations of petroleum hydrocarbons in the range of 2–46 μg/l in the water and 4–32 μg/g dry weight in the sediments taken from the vicinity of the field. In the same area, after a tanker fire accident, the concentrations of dissolved/dispersed

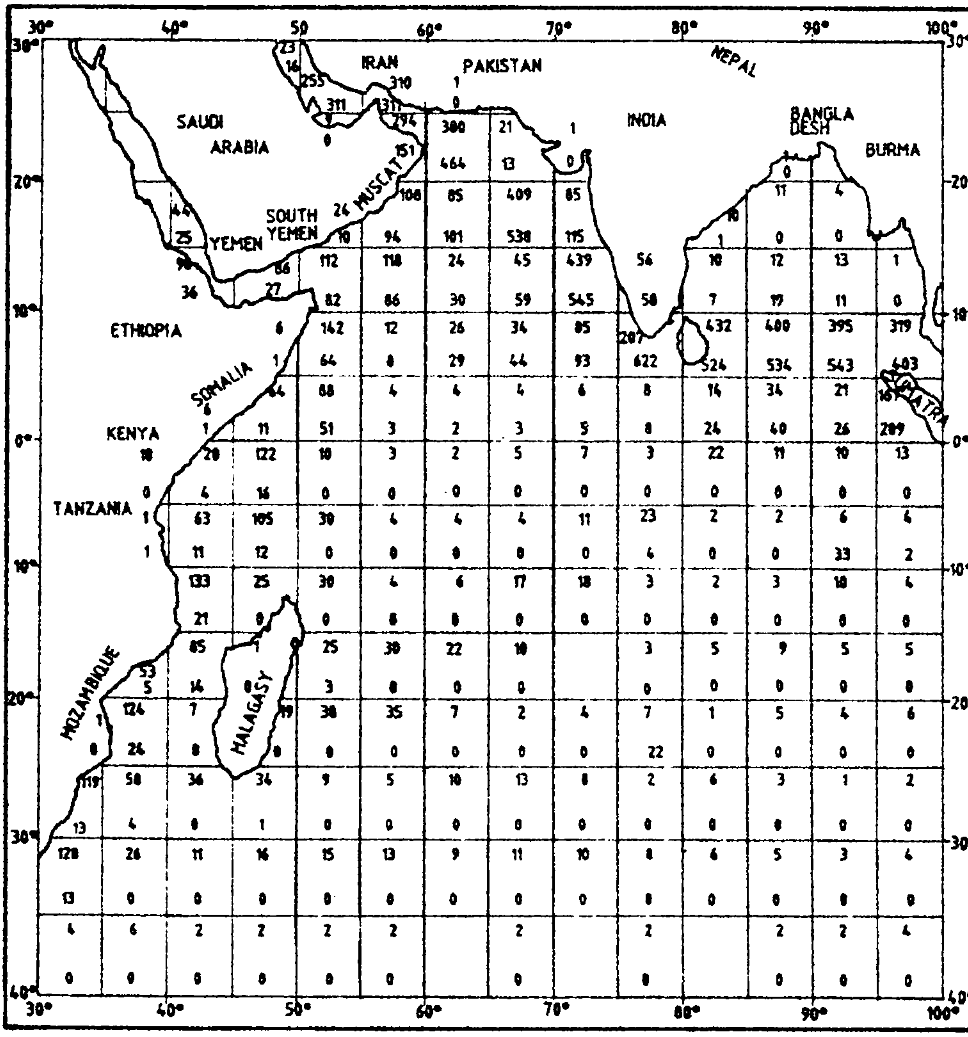

Figure 3. Record of observations of oil slicks in the Indian Ocean from 30° N to 40° S. The values are presented in 5° squares. Numbers at the lower end of the squares indicate the occasions when oil slicks were sighted. Numbers at the upper end indicate occasions when oil slicks were absent.

hydrocarbons went from 27–105 μg/l at the surface and from 36–59 μg/l at 5 m depth. The concentrations in the sediments increased from 1–26 μg/g to 40–512 μg/g after the accident.

3. Sensitive environments

Some specialised environments such as estuaries, coral reefs and mangroves are increasingly threatened and deserve special mention as they form spawning grounds and nurseries for a number of important species of economic value. They harbour a

Table 7. Dissolved/dispersed hydrocarbons in the upper 20 m of the Arabian Sea and the Bay of Bengal.

	Arabian Sea			Bay of Bengal		
Year	Transport (Million tonnes)	Concentrations (μg/kg) Range	Mean	Transport (Million tonnes)	Concentration (μg/kg) Range	Mean
1978	975	0·9–42·5	24·31	323	0–28·2	17·14
1979	1010	10·4–41·6	24·48	351		
1980	869	2·4–9·0	5·28	308	1·2–27·4	12·47
1981	725			270	0–4·5	2·25
1982	579			247	0–2·8	1·40
1983	513	0–17·7	5·02	222		
1984	489			252	0–3·4	1·70

wide variety of flora and fauna which can be sources of new drugs and raw materials for several industries.

India has 14 major, 44 medium and 162 small rivers. The mean annual runoff from these rivers is 1645 km^3, of which 1600 km^3 is the result of rainfall over the catchment areas and 45 km^3 is from the melting of the glaciers. A number of dams, barrages and canals in these rivers have been constructed to make their water available for agriculture, power generation and drinking.

Studies conducted on many of the estuaries have shown that most of these are either badly polluted or are getting contaminated mainly by industrial wastes. Almost all of the estuaries are tide-dominated, coastal plain type. Thus a fairly large amount of entrapped waste materials does not easily flow-out from the estuaries into the sea.

The estuaries of the rivers Ganga and Mahanadi have recently been studied for their water quality and recipient characteristics. Some of the physical, chemical and biological features of these estuaries over a period of 3 years have been studied (NIO 1986).

The river Ganga has an annual runoff of 493 km^3 and carries 616 $\times$ 10^6 tonnes of suspended solids. Nearly 396 $\times$ 10^6 m^3 of waste materials including 122 $\times$ 10^6 m^3 of industrial effluents are added annually to the estuarine region of this river. The river is influenced by semi-diurnal tides having a maximum range of 5·5 m during the spring tide. A zone of significant chemical reactions exists in the estuary. There is a clear addition of foreign material to this zone. About 85% of the dissolved metals settle within the river leaving only 15% to flow out. Nearly 10% of the suspended and particulate metals settle within the estuary, 50% at the confluence of the river with the sea and 40% finally flows out to the open sea.

Photosynthetic productivity and chlorophyll *a* decrease downstream. High zooplankton biomass is observed in the estuary, copepods being the dominant group. Numerous larvae and juveniles of commercially important fishes and prawns form another significant component. Microbes such as *Vibrio parahaemolyticus* which is the etiologic agent for food-borne gastroenteritis, are present in the water and sediments of the river mouth. These observations indicate that the water quality of the estuarine region of the river Ganga has deteriorated and needs immediate attention.

The northwest and southeast coasts of the Indian mainland as well as the Lakshadweep and the Andaman and Nicobar groups of islands harbour rich coral reefs and atolls of great beauty. It has been estimated that the lagoons of the Lakshadweep atolls contain upto 2000 MT of calcareous sands. Of this, about 700 MT upto one metre depth could be exploited without affecting the atoll environment adversely (Siddiquie 1985). However, due to oil pollution caused by a heavy tanker traffic in the vicinity and because of collections for ornamental shells and decorative objects and corals, some of the coral reefs on the islands of the Lakshadweep and Andaman and Nicobars are getting badly damaged. An island, in the Gulf of Kutch (Pirotan) has been declared as a nature reserve or marine park. Similarly, the islands of the Gulf of Mannar and Palk Bay in Tamil Nadu have also been declared as protected areas. Another coastal area with coral reefs near Malwan on the central west coast of India is likely to be declared as preserved.

The mangroves too form excellent hatcheries, nurseries and habitats for a wide variety of fish and wildlife. Land reclamation, deforestation for use of timber as firewood, population pressures and pollution are the main hazards for the mangrove environment. As an example, we can cite the case of Mahim creek where industrial wastes and domestic sewage have completely destroyed the once lush green mangroves found all along the creek.

4. Conclusion

Although the extent of pollution in the seas around India is not very severe, it is time we recognise that it needs a sustained scientific effort towards its improvement. The present, not so serious a situation, is largely due to the nature and geographical orientation of the northern Indian Ocean, which is subjected to the impact of semi-diurnal tides associated with the biannual reversal of the direction of monsoon winds and the resulting sea currents. These natural phenomena promote enough flushing and provide adequate exchange of water masses resulting into good dispersal of all the incoming pollution loads. Unlike the Baltic and the Mediterranean seas which are closed and therefore are heavily contaminated due to increasing inputs of land-based pollutants from countries surrounding them, we have the advantage of open seas that ensures good dispersal of the pollutant species. The seas should not be any more considered as dumping ground and this is the time we learn from the experiences of the other countries and evolve appropriate scientific programmes to keep our coastal waters free from pollution.

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