

# Marine Pollution Studies In India

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## INTRODUCTION

India has a long coastline of about 6000 km. The total land area is  $3.276 \times 10^6$  km<sup>2</sup>; of which  $1.65 \times 10^6$  km<sup>2</sup> or about 50% of the total is agricultural land. The exclusive economic zone (EEZ) of India, covering the area from coast to 200 nautical miles, is  $2.015 \times 10^6$  km<sup>2</sup> or about 61.5% of the total land area (Figure 1). The present population of India is around 680 million which is growing at the rate of about 2% per year (one baby is born every 2.5 sec). There are 2921 urban centres and 576,000 villages in the country. Of the urban centres, 142 are termed as class I (population 100,000), 192 as class II and 2587 as class III cities. Only 8 cities have complete sewerage and sewage treatment facilities. The rest are partially sewered or are not sewered at all. The country is fast developing in both industrial and agriculture sectors. This development is spread over both inland and in coastal areas.

It can, perhaps, be assumed that people living on the coast up to about 100 km inland are directly or indirectly dependant on the sea and its resources. This area contains about 25% of the total population and together they influence the health of the seas around India. The background information on population, area, pollutants added and other details are presented in Table 1. From the table it can be seen that the following problems will influence the coastal areas of the country and efforts are being made to examine them in some detail :

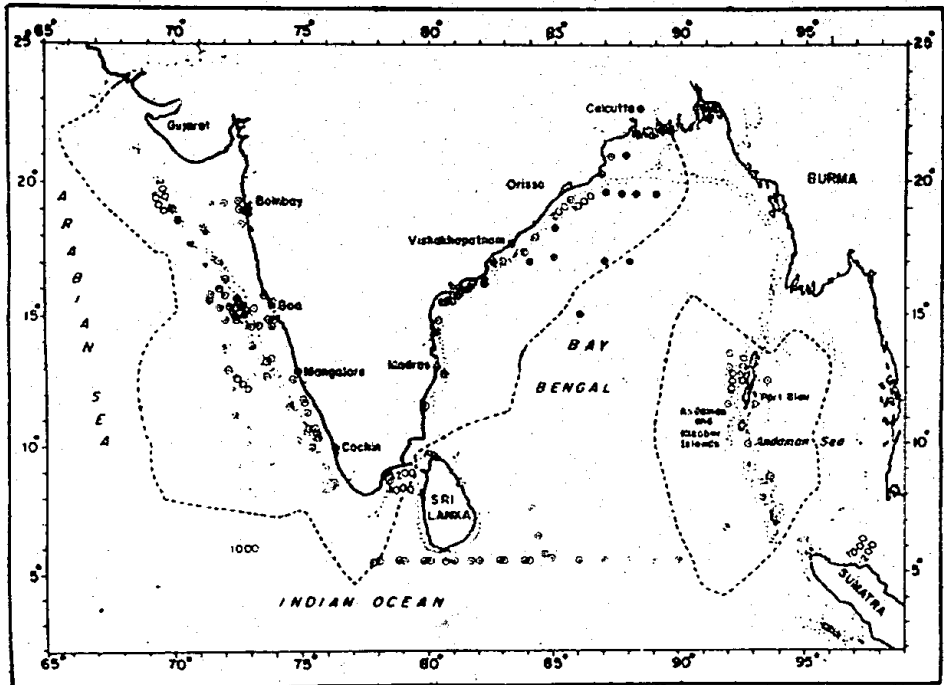


Figure 1. Area of study as reported in this paper. Within the dotted lines is the Exclusive Economic Zone of India.

- (a) Oil pollution
- (b) Heavy metal pollution
- (c) Pollution due to agricultural wastes.

Some of essential features connected with the marine pollution have been examined earlier by Qasim and Sen Gupta (1980).

## POLLUTION PROBLEMS

### OIL POLLUTION

Two of the world's largest oil tanker routes originate in the Gulf countries (Figure 2). One of them goes via the Mozambique Channel and South Africa to the western hemisphere. The other goes along the EEZ of India in the Arabian Sea, round Sri Lanka, across the southern Bay of Bengal to Far East and Japan. In 1981, 449 million tonnes (MT) or 62% of the total marine transport of 725 MT (B. P. 1981) from the Gulf countries were transported along the former route, while the rest was carried along the latter tanker route (Figure 2).

Data on 6689 observations related to the presence of oil slicks and other floating pollutants, obtained from the Japanese Oceanographic Data Centre, are presented for every 5° Square in Figure 3 (Sen Gupta and Kureishy, 1981). Numbers in the lower half of the squares indicate

Table 1. POPULATION AND RELATED DATA FOR INDIA AND SOME ESTIMATES OF POLLUTANTS ENTERING THE SEA AROUND INDIA (AS OF 1981).

Population	680 million
Coastal population (25% of total)	170 million
Land area	3.276 × 10 <sup>6</sup> km <sup>2</sup>
Agricultural area	1.65 × 10 <sup>6</sup> km <sup>2</sup>
Exclusive economic zone	2.015 × 10 <sup>6</sup> km <sup>2</sup>
River runoff (annual mean)	1645 × 10 <sup>6</sup> km <sup>3</sup>
Rainfall per year (on land)	3.4 × 10 <sup>12</sup> m <sup>3</sup>
Rainfall per year (on Bay of Bengal)	6.5 × 10 <sup>12</sup> m <sup>3</sup>
Rainfall per year (on Arabian Sea)	6.1 × 10 <sup>12</sup> m <sup>3</sup>
Domestic sewage added to the sea by coastal population per year (@ 60/head/day)	3.7 × 10 <sup>9</sup> m <sup>3</sup>
Industrial effluents added to the sea by Coastal industries per year	0.37 × 10 <sup>9</sup> m <sup>3</sup>
Sewage and effluents added by the rivers to the sea per year	50 × 10 <sup>6</sup> m <sup>3</sup>
Soild waste and garbage generated by coastal population per year (@ 0.8 kg./head/day)	50 × 10 <sup>6</sup> m <sup>3</sup>
Fertilizer used per year (@ 30.5 kg./ha yr <sup>-1</sup> )	5 × 10 <sup>8</sup> tonnes
Pesticides used per year	77000 tonnes
Synthetic detergents used per year	125000 tonnes
Oil transported across the Arabian Sea in 1981	725 × 10 <sup>6</sup> tonnes
Oil transported to western hemisphere in 1981	449 × 10 <sup>6</sup> tonnes
Oil transported to Far East and Japan in 1981	276 × 10 <sup>6</sup> tonnes
Tar deposition on beaches from Kutch to Kerala 1975	1000 tonnes
1976	750 tonnes

the number of times the oil was sighted. It can be seen from the figure that the intensities of oil are the highest along the two tanker routes. the percentage frequencies of oil sightings increase away from the source of origin of the oil and range from 79–90% along the route going west and from 74–87% along the route to the Far East. These would indicate that the percentage frequencies of oil sightings are the same along both the routes and the source of these oil slicks is probably the bilge-washings of the tankers when they are on their way to the Gulf ports.

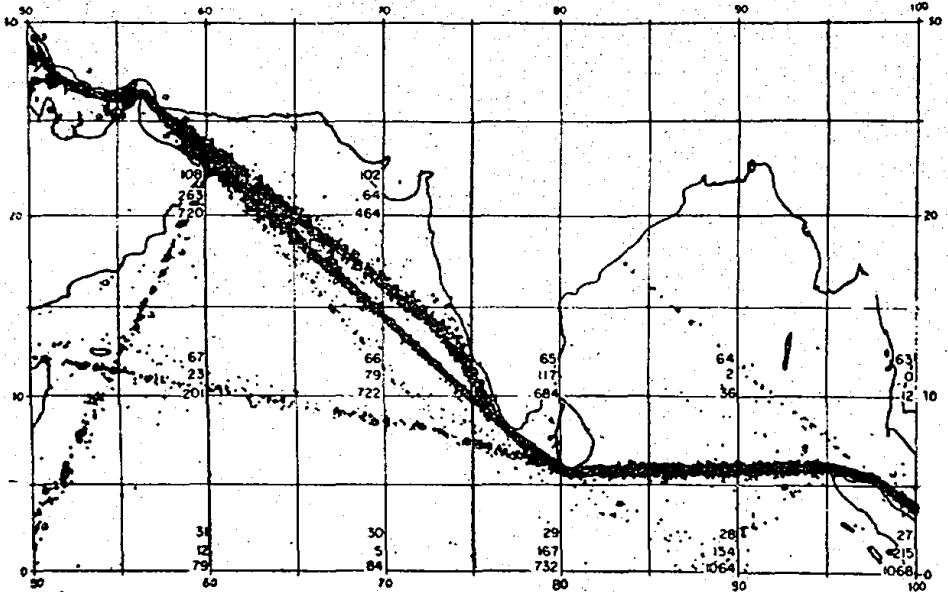


Figure 2. Each point in the figure refers to the presence of oil slick and other floating pollutants in the Northern Indian Ocean (courtesy: Japan Oceanographic Data Centre). Thickness of the lines, marking the tanker routes, indicates the intensity of occurrence of oil slicks.

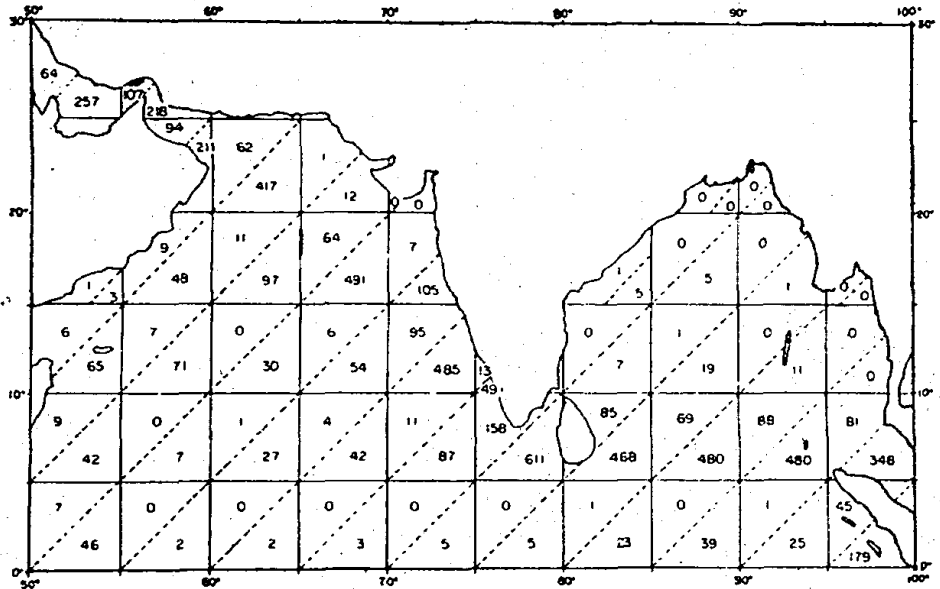


Figure 3. Observations on oil slicks and other floating pollutants every 5°-square in the Indian Ocean. All numbers in the lower half of the squares in all the lines indicate the total number of times the oil slicks were sighted. Numbers in the upper half of the squares in all the lines indicate the occasions when the oil slicks were absent.

Table 2 presents the observations on floating petroleum residues (tar balls) along both the tanker routes. Clearly the appearance of floating tar balls is on the increase in both the areas specially in the Arabian Sea.

Table 2. DISSOLVED/DISPERSED HYDROCARBONS AND PARTICULATE PETROLEUM RESIDUES (TAR BALLS) IN THE ARABIAN SEA AND BAY OF BENGAL.

		Dissolved/dispersed hydrocarbons ( $\mu\text{g}/\text{kg}$ )	
		Arabian Sea	Bay of Bengal
Coastal area	Surface : 8.6-31.0 (March 1978)		Surface : 0-2.3 (June 1978)
Tanker route	Surface : $17.1 \pm 4.1$ March 1978)		Surface : $21.7 \pm 1.0$ (June 1978)
	„ 21.5-42.8 (Dec. 1978)		„ $75.2 \pm 10.0$ (Feb. 1979)
	„ 18.6-41.6 (Dec. 1979)		„ 5.3-27.4 (Jan. 1980)
	„ 6.4- 9.0 (Feb. 1980)		„ 6.4-11.2 (Feb. 1980)
	„ 47 -230 (Oct. 1980)	10 m	23.2-26.9 (June 1978)
	„ 200-305 (Mar. 1981)		„ 22 -94 (Feb. 1979)
10m	0.9-22.9 (Mar. 1978)		„ 2.2-20.0 (Jan. 1980)
	„ 16.8-42.5 (Dec. 1978)		„ 3.1-13.6 (Feb. 1980)
	„ 16.9-34.5 (Dec. 1979)	20 m	13.1-28.2 (June 1978)
	„ 3.1- 6.3 (Feb. 1980)		„ 24-73 (Feb. 1979)
	„ 77-210 (Oct. 1980)		„ 1.6-27.1 (Jan. 1980)
	„ 130-267 (Mar. 1981)		„ 1.2-9.0 (Feb. 1980)
20m	25-28 (June 1978)		
	„ 28.6-37.5 (Dec. 1978)		
	„ 10.4-24.9 (Dec. 1979)		
	„ 2.4-4.5 (Feb. 1980)		

		Particulate petroleum residues (tar balls) $\text{mg}/\text{m}^3$	
		Arabian Sea	Bay of Bengal
Tanker route	0.02-0.32 (Mar. 1978)		0.42-3.45 (June 1978)
	1.26-3.46 (June 1978)		0 - 1.6 (Jan. 1980)
	0-0.54 (Dec. 1978)		0 - 69.8 (Feb 1980)
	0.09-6.0 (May 1979)		
	0-0.53 (Feb. 1980)		
	0.30-112.2 (Mar. 1981)		

From the data collected from 1978 to 1980 for the Arabian Sea, a range of 0 to 6.0 mg/m<sup>2</sup> with a mean of 0.59 mg/m<sup>2</sup> was observed. Using this value for the entire area of the Arabian Sea, from 0 to 25 N and from 50 to 80 E, within  $6.225 \times 10^6$  km<sup>2</sup> (Qasim, 1977), one obtains a figure of 3700 tonnes of floating tar balls at any one time of the year at the surface.

A recent observation during March 1981 along the oil tanker route off the west coast of India, between 12 and 19 N and 70 and 74 30' E, showed a range of 0.3 to 112.2 mg/m<sup>2</sup> with an average of 12.7 mg/m<sup>2</sup> for the floating tar balls. This may, perhaps indicate that oil pollution in the Arabian Sea is on the increase.

For the oil tanker route across the southern Bay of Bengal, between 5 and 7 N and 80 to 95 E, the range of concentration of floating tar balls is 0 to 69.75 mg/m<sup>2</sup> with an average of 1.52 mg/m<sup>2</sup>. The total area enclosed by these coordinates is  $0.73 \times 10^6$  km<sup>2</sup> (Qasim, 1977). Combining the area with the concentration, we arrive at a figure of 1100 tonnes for the total quantity of floating tar balls which can be expected to be present at any time along this tanker route. North of 7 N there is little or no accumulation of floating tar particles in the Bay of Bengal.

Accumulation of floating tar is entirely dependent on the surface currents. In areas of strong surface currents, e.g. Gulf stream in the North Atlantic and Kuroshio in the Northwestern Pacific, heavy accumulations of tar particles have been observed. In the Arabian Sea, off the west coast of India, the half yearly changes in the direction of the surface flow regulate the accumulation of tar particles.

The observed concentration in the North Atlantic ranged from 0.12–2.64 mg/m<sup>2</sup> with a maximum of 91.8 mg/m<sup>2</sup> (Levy and Walton, 1976). Similar accumulation in the Northwestern Pacific ranged from 0.02–13.3 mg/m<sup>2</sup> (Sano et al., 1979). Thus the oil tanker routes in the Northern Indian Ocean are as much polluted as those in the other oceans.

Assuming that the abundance of oil entering any marine area is proportional to the volume transported, an attempt has been made to compute the entry of tar into the Arabian Sea and Bay of Bengal. Since the best estimate of the total input of oil from all sources to the world oceans in 1973 was taken to be 6.11 MT, it follows that on a world-wide basis, the average input would be 0.36% of the total flow (Levy and Walton, 1976). If it is assumed that this percentage did not change from 1973–1981, the amount entering the Arabian Sea and the Bay of Bengal each year can easily be calculated. The volume transported across the southern Bay of Bengal has been taken as 35% of the total transport across the Arabian Sea. The results obtained are presented in Table 3.

Table 3. VOLUME OF OIL TRANSPORTED ACROSS THE SOUTHERN BAY OF BENGAL AND THE ARABIAN SEA

Year	Flow in 10 <sup>6</sup> tonnes over		Total world flow (10 <sup>6</sup> tonnes)	Entry of (a) oil in 10 <sup>6</sup> tonnes to		Entry (b) of tar in tonnes to	
	Arabian Sea	Bay of Bengal		Arabian Sea	Bay of Bengal	Arabian Sea	Bay of Bengal
1973	990	346	1694	3.6	1.2	36000	12000
1974	992	347	1656	3.6	1.2	36000	12000
1975	918	321	1508	3.3	1.2	33000	12000
1976	1033	361	1706	3.7	1.3	37000	13000
1977	1024	358	1724	3.7	1.3	37000	13000
1978	975	341	1691	3.5	1.2	35000	12000
1979	1009	353	1752	3.6	1.3	36000	13000
1980	870	313	1590	3.1	1.1	31000	11000
1981	725	276	1427	2.6	1.0	26000	10000

(a) Based on  $(6.11/1694) \times 100 = 0.36\%$  rate of loss for 1973

(b) Based on 1% converted to tar

Arabian Sea Average entry = 34100

Tar present = 3700

Residence time =  $3700/34100 = 0.11$  year or 40 days

Bay of Bengal Average entry = 12000

Tar present = 1100

Residence time =  $1100/12000 = 0.09$  year or 33 days

(Source: Sen Gupta and Qasim, 1982)

Although the fraction of the original input of oil that persists long enough to be transformed into tar differs for oils of different origins, as a first approximation it can be assumed that about 1% of total input will ultimately end up as tar. This seems to be fairly well applicable to the Arabian Sea, as the entire volume transported across it has the same source of origin, i.e. the oil from the Gulf countries. This leads to a range in the quantity of tar in the Arabian Sea from 26,000 in 1973 to 37,000 tonnes in 1981. The range in the quantity of tar for the southern Bay of Bengal for the same period is from 10,000–13,000 tonnes. However, resistant as it may appear, tar in itself is not immune to weathering and has a limited lifetime on the

surface of the ocean. The amount of tar present at any one time on the surface of the Arabian Sea has been calculated as 3700 tonnes. On the basis of the average annual entry over the period 1973-1981, the "residence time" of tar in the Arabian Sea would be about 0.1 year or about 40 days. Calculating the same way the 'residence time' of tar in the Bay of Bengal comes to about 0.09 year or about 33 days.

The average tar concentration on the surface of the North Atlantic has been calculated as 5200 tonnes and its "residence time" is about 58 days (Levy and Walton, 1976).

From the above, one can assume that tar occurring on the sea surface remains more or less unchanged for 30-60 days.

Dissolved/dispersed hydrocarbons or petroleum residues, estimated by the method given by UNESCO (1976) using UV-spectrophotometry and spectrofluorometry are also presented in Table 2. Concentrations appear to vary with time depending upon the intensity of the tanker traffic and the prevailing meteorological conditions. The values do not seem to change significantly in the upper 20 metres. Using the average values in relation to the volumes of water in the upper 20 metres, it has been estimated that about 4 MT of dissolved petroleum residues will always be present in upper layers of the Arabian Sea and 0.4 MT in the upper 20 metres of the southern Bay of Bengal (Sen Gupta and Kureishy, 1981).

In recent year, the trends in the production of oil and its transport both in the world and in the the Gulf countries are on the decrease (Figure 4). A significant decline has also been found in the marine transport of oil from 1974-1981. If a similar trend continues, oil pollution in the Arabian Sea and Bay of Bengal can at least be expected to stabilize if not decrease.

Observations on the collection of tar on the beaches along the west coast of India showed that the deposition of tar balls occurs only between April and October every year. This is the period of southwest monsoon, when a shoreward component of the coastal currents develops. During the rest of the year, there is practically no deposition anywhere. Two years observations on most of the beaches along the west coast of India (Table 1) gave a range of 0-1390 g/m<sup>2</sup> for 1975 and 0-760 g/m<sup>2</sup> for the year 1976. The average values for the two years were found to be 28 and 20 g/m<sup>2</sup> respectively. The total deposition on all the beaches worked out to 1000 tonnes for 1975 and 750 tonnes for 1976 (Dhargalkar et al., 1977).

Some measurements of the concentration of petroleum hydrocarbons in the organisms and sediments along the coastal regions of India have been made recently. Data collected so far indicate a range of 19.5-83.3 µg/g dry weight in plankton and 4.8-8.5 µg/g dry weight in the top-most layers of the sediment (Fondeker et al., 1980).



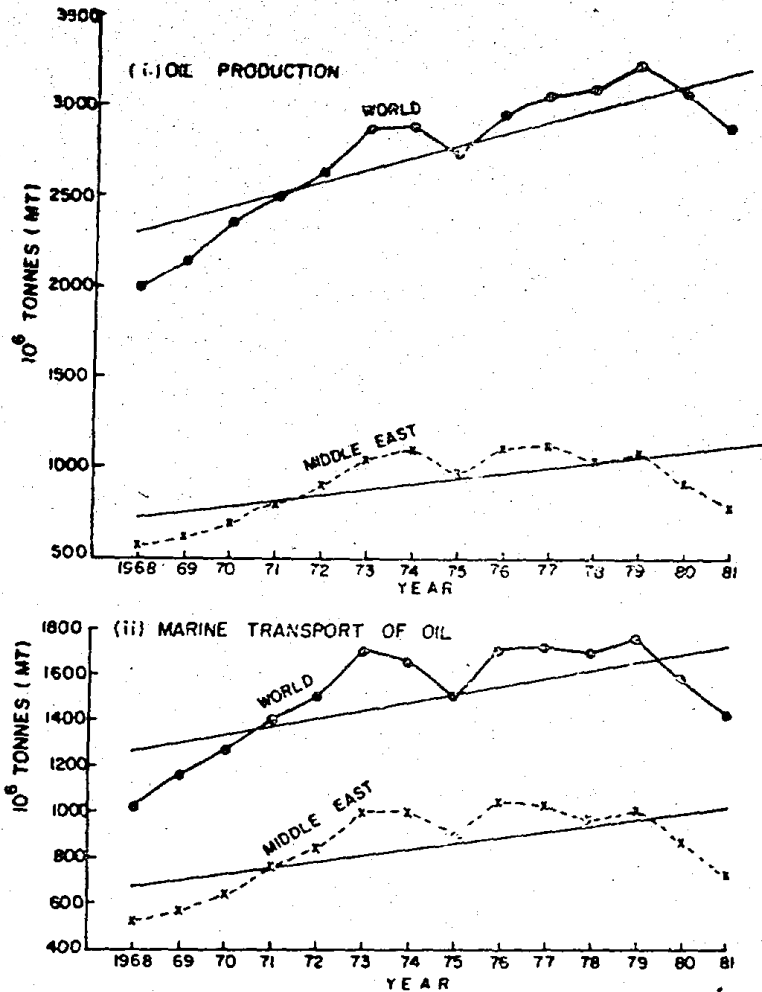


Figure 4. Growth of oil production and its marine transport including the contribution from the Middle East countries (Source : British Petroleum, 1981) From 1968 to 1981.

In recent year, a series of laboratory experiments were carried out on several physical and chemical methods to be used for fighting oil pollution in the event of an accidental oil spill (Bhandare and Sen Gupta, 1976; Fondekar et al., 1977; Verlencar et al., 1977; Solimabi and Topgi, 1978). Several brands of indigenously manufactured polyurethane foam and chemical dispersants were tested for their efficiency and suitability in the removal of spilled oil. Static bioassay tests were carried out on molluscs and prawns to evaluate the toxicity of the chemical dispersants both singly and in combination with the crude oil (D' Silva and Row, 1982). Many British, US and Indian manufacturers and also the Oil and Natural Gas Commission (ONGC) of India periodically send samples of dispersant to National Institute of Oceanography (NIO) for conducting similar tests to judge their

suitability to Indian conditions. A model study, using historical data on winds, waves and currents along the west coast of India, were made to forecast the movement of a hypothetical oil spill in the Bombay High region in each month of the year (Gouveia and Kurup, 1977). At present, harbour authorities of Bombay and the ONGC are equipping themselves with both physical and chemical protective measures to fight an accidental oil spill.

#### HEAVY METAL POLLUTION.

Heavy metal pollution in the seas around India is largely caused by the discharge of industrial waste into the Sea. Studies on this form of pollution were initiated in 1977. Since then, regular monitoring activities are being carried out in the seas around India. Particular emphasis is being given to coastal areas with heavy concentrations of industries.

Available data have been separated into essential and non-essential heavy metals.

#### ESSENTIAL HEAVY METALS

In Water copper, iron manganese, zinc, cobalt and nickel have been classified as essential heavy metals. These metals, are known to help in the growth and production of marine life.

Data on the concentrations of some of the heavy metals from the Indian Ocean are given in Table 4. The values shown in this table do not indicate any variation with depth or regions, although the samples were collected from different areas and different depths and also include some coastal regions. The large range obtained was probably due to different analytical techniques used. The range are Cu 0.08-49.1; Cd 0.01-88; Fe 0.10-96; Mn 0.07-80; Zn 0.3-42.4; Pb 0.02-7; Ni 0-16.3; and Co 0-7.9 all in  $\mu\text{g/l}$ . The data on trace metals have been subjected to necessary statistical treatment and hence only the reliable values have been reported.

The average values of some of the metals from the inshore and off-shore areas of the Arabian Sea and Bay of Bengal are given in Table 5. Their ranges in the surface layer (10 m) in dissolved form for the Arabian Sea are: Cu 2.5-22.5; Fe 10-66.9; Mn 7.7-16.6; Zn 2.9-42.4; Co 0.6-5; and Ni 1-16.3 all in  $\mu\text{g/l}$ . Similar ranges for the Bay of Bengal are: Cu 1.2-17.5; Fe 2.0-237.5; Mn 1.5-39.3; Zn 1.9-173.8; Co 0.5-12 and Ni 0.8-30.3 all in  $\mu\text{g/l}$ . Almost all the high values came either from the coastal waters or from the vicinity of oceanic islands (Laccadive and Andamans).

Surface waters of the Bay of Bengal had a higher range for almost all the metals as compared to those in the Arabian Sea. This

Table 4 RANGES OF DISSOLVED HEAVY METAL CONCENTRATIONS ( $\mu\text{g/l}$ ) IN THE INDIAN OCEAN

Source	Cu	Cd	Fe	Mn	Zn	Pb	Ni	Co	Hg( $\text{ng/l}$ )
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	—
Singhal et al. (1978)	—	—	—	—	—	—	—	—	13-187
Sanzgiri and Moroes (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)	—	—	—	—	—	—	—	—	0-204
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	—

Table 5 RANGES OF METAL CONCENTRATIONS IN DISSOLVED (D) IN  $\mu\text{g/l}$  AND PARTICULATE (P)  $\mu\text{g/g}$  (DRY WEIGHT) IN WATER

Depth Range	Cu		Fe		Mn		Zn	
	D	P	D	P	D	P	D	P
Arabian Sea								
Surface (10 m)	2.5-22.5	7-274	10-66.9	52-14100	7.7-16.6	3-670	2.9-42.4	18-40950
10-100	1.7-22.5	4-551	4.5-66.9	52-14100	3.8-37	3-670	1.8-42.4	18-40950
100-500	2.1-17.5	2-184	7.2-136.2	70-5150	3.8-80	2-160	1.2-37.9	29-17680
500-1000	1.9-17.5	2-184	9.2-136.2	70-3416	1.8-80	4-100	3-31.2	31-30940
1000 and below	1.9-15.7	13-184	15.7-96	138-2384	1.8-40.2	5-21	2-11.2	117-260
Bay of Bengal								
Surface (10 m)	1.2-17.5	10-4834	2.0-237.5	288-798195	1.5-39.3	8-104300	1.9-173.8	100-129100
10-100	1.0-37.2	9-4834	2.0-237.5	345-798195	1.3-40.8	18-104300	1.9-173.8	22-129100
100-500	1.0-11.3	9-3767	2.5-72	247-44182	1.3-40.8	3-696	1.1-65.3	17-10885
500-1000	1.5-36.3	18-3767	2.5-71.5	247-44182	1.3-37	3-3152	1.1-32	ND-10885
1000 and below	1.5-9.5	34-2764	3.8-71.5	185-17562	2.5-37	113-290	4.8-20	65-10200

Depth Range	Co		Ni		Cd		Pb		Hg	
	D	P	D	P	D	P	D	P	D	P
Arabian Sea										
Surface (10 m)	0.5-5	55-153	1-16.3	33-203	0.2-3.5	2-13	4-12.5	ND-173	0.03-0.2	—
10-100	0.5-6.7	55-181	0.6-16.3	14-203	0.1-3.8	2-16	25-15.2	14-224	0.03-0.20	—
100-500	0.5-6.7	70-181	0.6-16.1	13-87	0.1-0.8	3-25	1.8-27.3	12-214	0.03-0.09	—
500-1000	0.5-6.6	68-144	1.8-16.1	13-152	0.3-0.8	3-25	1.8-27.3	12-359	0.03-0.16	—
1000 and below	0.8-1.9	30-100	1.9-5.6	16-152	0.4-0.8	3-11	2.7-7.5	50-359	0.03-0.16	—
Bay of Bengal										
Surface (10 m)	0.5-13	17-17150	0.8-30.3	12-14950	0.3-2.9	2-13034	0.5-21.8	31-39900	0.05-0.27	—
10-100	0.5-13	17-17150	0.8-30.3	12-14950	0.3-4.2	2-13034	0.5-21.8	31-39900	0.05-0.22	—
100-500	0.8-5.2	63-14714	1.7-7.7	14-146	1.5-4.2	3-2660	0.2-7.8	46-1447	0.06-0.25	—
503-1000	1-3.3	37-14714	0.5-6.8	18-590	0.5-2	11-2660	0.5-7.8	124-1447	0.06-0.25	—
1000 and below	1.2-7.9	23-1223	4.4-11.2	18-590	0.6-1.5	33-66	0.5-5.0	60-2881	0.07-0.12	—

Sources: Sen Gupta et al. (1978), Singbal et al. (1978), Sanzgiri et al. (1979), Sanzgiri and Moraes (1979), Braganca and Sanzgiri (1980), Sanzgiri and Braganca (1981). ND — Non-detectable.

difference appears to be because of the large volume of river runoff (~1350 km<sup>3</sup>/year from the Indian rivers) which the Bay of Bengal receives.

Vertical distribution of metals, both in dissolved and in particulate forms, is caused by the oxidation-reduction processes occurring in the water column and by the characteristics of the different water masses.

*In Biota.* Values of the metals in zooplankton and in some of the fishes from the Arabian Sea and Bay of Bengal are given in Table 6. In fishes the values are from the muscles. In zooplankton the range of each metal was as follows: Cu 2.0-5.0; Fe 35.0-94.0; Mn 3.0-7.0; Zn 8.0-31.0; Ni 0.2-3.0; and Co 0.2-3.0 all in ppm wet weight. In fishes the range was Cu 0-1.7; Fe 4.0-164.0; Mn 0-10.0; Zn 2.0-21.0; Ni 0-4.0; and Co 0-3.8 all in ppm wet weight. No strict correlation between length, weight, stage of maturity and the concentration of metals was observed.

Laboratory studies on the bioaccumulation and elimination of copper and zinc in the green mussel and rock oyster, have been reported by several authors (Nair et al., 1977; D'Silva and Kureishy, 1978; D' Silva and Qasim, 1979). Similarly, the concentrations of some of the essential metals in the mangrove foliage at selected localities along the Indian coast have been reported by Agadi et al., (1978)

Another element utilized for the growth of certain marine organisms is the metalloid arsenic. However, the excess of this metal is harmful to fishes. Experimental data on the tolerance of fishes to arsenic have been collected and regular monitoring of this metal in the water, sediments and fishes is being carried out.

#### NON-ESSENTIAL HEAVY METALS

*In Water.* Mercury, lead and cadmium belong to the group of non-essential heavy metals. They are ubiquitous in sea water but mostly occur at very low concentrations often below the detection limits of the analytical methods used.

Observations on the mercury in marine environment were started in 1977. Lead and cadmium were analysed from 1979 onwards. Data collected on these metals in dissolved and particulate form are presented in Table 5. On several occasions, the values were found below the detection limit. These have not been included while determining the values given in Table 5. The range in the surface values of dissolved fractions of the three metals in the Arabian Sea were: Hg 0.03-0.2; Pb 4-12.5; and Cd 0.2-3.5 µg/l; and in the Bay of Bengal: Hg 0.05-0.27; Pb 0.5-21.8; and Cd 0.3-2.9 µg/l.

The source of all these metals appears to be atmospheric transport

Table 6 CONCENTRATION OF HEAVY METALS (ppm WET WEIGHT) IN ZOOPLANKTON AND MUSCLES OF CERTAIN FISHES FROM THE NORTHERN INDIAN OCEAN.

Organism	Cd	Cu	Mn	Zn	Fe	Pb	Ni	Co	Hg
Zooplankton	0.7-6	2.5	3-7	8-31	35-94	4-7	0.2-3	0-4	0
Perch									
Pelates quadrilineatus	0-0.1	0.2-0.3	0-0.1	3.4-6.1	6-29	0.8-1.0	0.3-0.5	0	0.03-0.10
Jewfish									
<i>Johnius osseus</i>	0.2-0.4	0-0.8	0.3-1.0	4-4.8	6-8	0.2-1.1	0	0.7-1.1	0.01
Mackerel									
<i>Rastrelliger kanagurta</i>	0.2	1.0	0.01	6	12	0	0	1.8	0.01
Sardine									
<i>Sardinella longiceps</i>	0-0.2	0-0.3	0.2	4.5-6.3	8-10	0	0	0.7-1.1	0-0.1
Dolphin fish									
<i>Coryphaena hippurus</i>	0-0.9	0.2-1.7	0-3.1	5-9	13-39	0-3.4	0.1-1.2	0-1.9	0.01-0.14
Barracuda									
<i>Sphyræna picuda</i>	0-0.3	0.1-0.5	0.2-3.1	3.3-5.8	4-17	0-0.3	0.1-0.3	0.6-1.9	0.07-0.2
Sharks									
<i>Eulamia elioti</i>	0-0.8	0.2-1.1	0-2	4.5-12	10-57	0.9-6.0	0-0.3	0-3.8	0.08-0.19
Flying fish									
<i>Cypselurus comatus</i>	0-0.1	0.1-0.7	0-3.7	4-21	4-62	1.1-3.8	0-0.9	0.2-1.3	0.01-0.07
Skipjack Tuna									
<i>Katsuwonus pelamis</i>	0-0.4	0.3-1.3	0.1-7.5	4-8	7-164	0-1.4	0-1.0	0-3.2	0.03-0.22
Malabar Trevally									
<i>Carangoides metabaricus</i>	0-0.6	0-0.7	0.1-9	2-5	5-11	0-0.3	0-0.6	0-1.2	0.02-0.08
Yellowfin Tuna									
<i>Neothunnus macropterus</i>	0.1-0.3	0.6-3.0	0.5-0.8	4-12	11-25	0-3.0	0.4-4.0	0.7-1.5	0.02-0.23

Sources: Kureishy et al. (1979, 1981)

and industrial waste. However, mercury can also be contributed as a result of weathering and leaching from the deposits found in crustal rocks of the hinterland. There are a few such areas along the Indian coast and concentrations ranging from 0.2–0.41  $\mu\text{g/l}$  have occasionally been recorded from the areas far away from any coastal industrial belt (Singbal et al., 1978).

*In Biota.* Table VI shows the results of the analysis of the three metals in zooplankton. Mercury in zooplankton was found to be absent while lead in the samples collected from the Bay of Bengal was fairly high. The possible cause of this is being investigated. From Table 6 it is clear that sharks and skipjack tuna have the highest concentrations in their muscles.

In the Northern Indian Ocean (Table 7), the highest values of the three metals were found in the liver. However, the concentrations recorded in the muscle are still much lower than the internationally accepted minimum of 0.5 ppm.

**Table 7** RANGES OF CONCENTRATION OF A FEW NON-ESSENTIAL HEAVY METALS (PPM WET WEIGHT) IN DIFFERENT PARTS OF FISHES FROM THE NORTHERN INDIAN OCEAN

Body parts	Mercury	Cadmium	Lead
Muscle	0–0.22	0–0.9	0–6.0
Liver	0–0.04	1.2–83.7	0–8.7
Gill	0–0.03	0–0.4	0.8–7.0
Heart	0–0.08	0–3.4	0–3.4

Sources: Kureishy et al. (1979, 1981)

In the muscles of several important food fishes from the inshore region and from a polluted bay (Thana Creek) of Bombay, several authors reported very high values (Tejam and Haldar, 1975; Rama and Somayajulu, 1972).

In 1980, the values of mercury in the water, in crab muscles and sediments from the same region increased even further (Ganesan et al., 1980). A close look at Table 8 would reveal that the situation is indeed alarming though a decrease in the concentration has been recorded away from the coast.



Table 8 MERCURY POLLUTION IN AND AROUND BOMBAY CITY

Components	Distance from shore				Thana Creek	
	Coast	1 km	1.5 km	2 km	3 km	
Water ( $\mu\text{g/l}$ )	1.4-23.0	12-29	10-35	9-30	14	42
Crab muscles (ppm wet weight)	0.2-4.1	0.1-1.5	0.2-1.0	0.3-1.3	1.8	7.3
Sediment (ppm dry weight)	0.1-27.0	—	—	—	—	38

Source: Ganesan et al. (1980)

#### POLLUTION FROM AGRICULTURAL WASTES

Fertilizers, pesticides and insecticides are widely used in India in agriculture and pest and vector control. Organochlorine pesticides have not yet been banned although the use of organophosphorus and carbamate pesticides is being encouraged.

The average quantity of fertilizers used in India is  $30.5 \text{ kg ha}^{-1} \text{ yr}^{-1}$  which would give an annual total of  $5 \times 10^8$  tonnes for the entire agricultural land in the country (Table 1). About 77,000 tonnes of pesticides were used in 1980 for different purposes and the figure for synthetic detergents is 125,000 tonnes. There is a progressive increase in the use of both pesticide and detergent every year.

Probably about 25% of these chemicals finally reach the coastal waters resulting in an increase in the nutrient pool, particularly phosphates, ammonia and urea.

An examination of the data collected over a period of 15 years has revealed an increase of about 50% in the ambient concentration of phosphate-phosphorus in the waters off Bombay (Sen Gupta and Sankaranarayanan, 1974). In the coastal region of Madras an unusually high level of phosphate-phosphorus in the upper 10 metres of water, has been recorded during several cruises of RV GAVESHANI.

Periodic mortality of marine fauna due to excess of ammonia in the water has been observed near the discharge point of fertilizer factories. Urea concentration is also reported to be high in these areas. However, neither anoxic condition nor eutrophication, as a result of these nutrient additions, have been noted anywhere in the coastal regions.

Only a few measurements of DDT and its metabolites in zooplankton have been made so far (Kureishy et al., 1978). In most cases, the values were found to be below the detection limit of the gas chromatography-mass spectrometry.

graphic method used. There was a direct relationship between the DDT concentration and the lipid content of plankton. The presence of BHC and PCB was also detected in the samples.

### INPUT STUDIES

Data on the input of different cations and anions to the Indian Ocean are very scanty. Background information on the sources of input, e.g. river runoff, silt load, volume of domestic sewage and industrial effluents, rainfall and aerosol are not readily available.

Most of the cations and anions added to the oceans are absorbed on to the silt particles. Considering the enormous amount of silt added annually to the Indian Ocean, i. e.  $34 \times 10^8$  tonnes, of which  $16 \times 10^8$  tonnes is the contribution from the Indian rivers (Holeman, 1968), siltation is probably one of the principal sources of input.

The average concentrations of some elements in the rain water from the coastal regions of India have been reported as follows: Na 4.6; Cl 6.8; Ca 1.34; Mg 0.51; K 1.02 all in mg/l Mn 23.4; Br 33.6; I 13.3 all in  $\mu\text{g/l}$  (Sadasivan, 1979); Fe 4.3; Co 0.1; Ni 0.1; Cu 6.8; Zn 13.3; Pb 21.5 all in  $\mu\text{g/l}$  (Fondekar and Topgi, 1979). Aerosol contents over the Indian Ocean varies from 1.4 to 68  $\text{mg/m}^3$  air. It decreases southwards with the latitude and becomes almost zero close to the Antarctic Continent (unpublished data). From these values it can be inferred that the atmospheric flux of the elements is not very significant and the major transport route of the pollutants to the Indian Ocean is through the riverine source.

The present state of pollution in the marine environment can be clearly evaluated if the concentrations of the elements in the oceans are compared with those in largely uncontaminated areas, e. g. Greenland glacier, Himalayan glacier, Antarctic ice and Antarctic lake. Samples from the Himalayan glacier, Antarctic ice and Antarctic fresh water lake have been analysed for some of the elements (Sanzgiri; Naik, D' Souza and Sen Gupta, unpublished results). For the Himalayan glacier the mean concentrations were: Fe 82.5; Cu 4.1; Mn 17.0; Zn 4.5; Cd 0; Pb 3.1; Co 1.1; Ni 3.4 all in  $\mu\text{g/l}$ ; and F 0.1; Br 0.7; I 0; Ca 1.6; Mg 5.0; K 3.2 in mg/l. While in the surface water of an Antarctic lake they were; Fe 50.5; Zn 13.6; Cu 3.4; Mn 5.6; Cd 0; Pb 0; Co 0; Ni 3.2  $\mu\text{g/l}$ ; and F 0.5; Br 0.7; I 0; Ca 107.0; Mg 67.1; K 54.3 in mg/l. When these values are compared with those occurring in rain water and in the seas around India, it can be concluded that their input in the sea comes largely from landbased sources.

### IMPACT ASSESSMENT

From the information summarized above, it is clear that the data collected so far are not comprehensive enough to have a clear understand

ing of the total pollution load which the seas around India receive. However, the data indicate that the region as a whole is not yet seriously affected. Localized problems, both short term and long term, do appear from time to time and their magnitude varies from place to place.

The problem which is of the maximum concern to India is oil pollution. Because of the transportation of a large volume of oil through the Arabian Sea and Bay of Bengal, many areas receive large quantities of oil every year. The worst affected ecosystems seem to be coral reefs and sandy beaches. Significant damage has already been noticed on some of the atolls of Lakshadweep and in the coral reefs of the Nicobar group of islands.

Other possible impact can be expected to come from the disposal of untreated or partially treated domestic sewage and industrial wastes. Continued washings by rain water of fertilizers, pesticides, herbicides and insecticides, due to their widespread use, can also pose problems.

India's population is increasing progressively every year at the rate of about 13 million per year. Thus, the annual increase in the pollutants to our seas can be expected to be of the order of  $71 \times 10^6$  m<sup>3</sup> sewage,  $7 \times 10^6$  m<sup>3</sup> industrial wastes and  $1 \times 10^6$  tonnes of garbage. A significant percentage of all these finally reach the sea by the land and river runoff. As we know today, the capacity of the oceans to act as a sink is not unlimited.

Being located in the equatorial and tropical region, India has the advantage of receiving the impact of semi-diurnal tides. The tidal range varies from about 1 m at the southern tip of the peninsula to about 8 m at the northern extreme of the west coast and to about 6 m at the mouth of the river Ganga on the east coast.

Tidal flushings twice a day, associated with the bi-annual reversal of the direction of monsoon winds and the resultant surface currents associated with an even bottom topography help in dispersing and diluting the pollutants and reducing the magnitude of their impact on the marine environment considerably.

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