

Inputs from Indian rivers to the ocean : A synthesis

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Abstract - Indian rivers contribute about 4% of the global annual discharge, of which the major rivers contribute $126 \times 10^{10} \text{ m}^3 \text{ y}^{-1}$ to the Bay of Bengal which is approximately four times that to the Arabian Sea ($29.7 \times 10^{10} \text{ m}^3 \text{ y}^{-1}$). Fluxes of chemical substances to the Indian Ocean from these rivers are computed to a first approximation. The major ion contents are inversely proportional to the river runoff especially for the rivers entering the Arabian Sea. The Bay of Bengal receives nearly four times more total dissolved solids (TDS, $207 \times 10^{12} \text{ g y}^{-1}$) than that received by the Arabian Sea ($55 \times 10^{12} \text{ g y}^{-1}$), which also is the case for major ions. On an average Indian rivers are enriched in major ions, except Na, compared to the average world river. Indian rivers contribute about 7% of TDS flux to world oceans annually. Results reveal that $52 \times 10^9 \text{ g y}^{-1}$ and $61 \times 10^9 \text{ g y}^{-1}$ of phosphate and nitrate, respectively, are being added by the Indian rivers to the Indian Ocean. The estimated total, dissolved plus particulate, ^{238}U input to the Bay of Bengal from the Indian rivers is $8 \times 10^9 \text{ g y}^{-1}$. Dissolved organic carbon is being added at a rate of $4 \times 10^{12} \text{ g y}^{-1}$ whereas the rate for particulate organic carbon is $1.4 \times 10^{12} \text{ g y}^{-1}$. Total fluxes of Na, K, Mg, Ca and HCO_3^- to the Indian Ocean are 18, 4, 10, 35 and $145 \times 10^{12} \text{ g y}^{-1}$, respectively. Suspended Al, Fe, Mn, Ni, Cu and Zn are added together at rates of $3.5 \times 10^{12} \text{ g y}^{-1}$ into the Bay of Bengal and $0.8 \times 10^{12} \text{ g y}^{-1}$ into the Arabian Sea. These estimates represent the minimum fluxes since the removal processes are considered to the maximum wherever necessary.

INTRODUCTION

Knowledge of river inputs of substances to the oceans is essential to understand the material fluxes and balances on a global scale. Attempts have been made to estimate material fluxes to oceans from the major rivers of the world including the Ganges from the Indian subcontinent (MEYBECK, 1979; MARTIN and MEYBECK, 1979; MARIN and WHITFIELD, 1983). Systematic studies on Indian rivers had not been made before 1970's, but considerable attention is being paid thereafter. In the paper we attempt to estimate the fluxes of elements carried to the Indian Ocean by rivers on the subcontinent and discuss the constraints involved and make recommendations for future research.

For the global freshwater discharge rate of $37.4 \times 10^{12} \text{ m}^3 \text{ y}^{-1}$ (MARTIN and WHITFIELD, 1983) the Indian rivers contribute $1.675 \times 10^{12} \text{ m}^3 \text{ y}^{-1}$ (RAO, 1975), of which the major rivers contribution is $1.56 \times 10^{12} \text{ m}^3 \text{ y}^{-1}$. However, the Indian rivers carry a disproportionately large amount of suspended load ($2.873 \times 10^{15} \text{ g y}^{-1}$) as compared to the mean suspended load to world oceans of the order of $8 \times 10^{15} \text{ g y}^{-1}$ (MILLIMAN and MEADE, 1983). In addition to the Ganges, Brahmaputra and Indus, which are among the major rivers of the world, about 46 rivers flow into the Indian Ocean from the subcontinent. These include Godavari, Krishna, Mahanadi, Narmada, Cauvery and Tapti which are significant in the present context. Fig.1 shows the major rivers of the subcontinent and their flow paths before they drain into the Arabian Sea and the Bay of Bengal. As is obvious from Fig.1 almost the entire subcontinent serves as a basin for these rivers. The river discharge is generally proportional to the drainage area of the respective basins (Fig. 2). Despite the large catchment area of the Indus river compared to the Ganges and Brahmaputra rivers, the runoff of the former is less than those of the latter rivers (Fig.2). The total discharge from the subcontinent, including minor ones, as evaluated from the data of SUBRAMANIAN (1979), is $160 \times 10^{10} \text{ m}^3 \text{ y}^{-1}$. The discharges from major rivers into the Bay of Bengal and the Arabian Sea are 126×10^{10} and $29.7 \times 10^{10} \text{ m}^3 \text{ y}^{-1}$,

respectively. Hence, freshwater discharge to the Bay of Bengal is nearly four times that to the Arabian Sea. Maximum runoff occurs during monsoon season (RAO, 1975; UNESCO, 1971) and during this period the amount of precipitable water in the Indian atmosphere also reaches maximum values of ca. 6 g m^{-2} (RANGARAJAN and MANI, 1982).

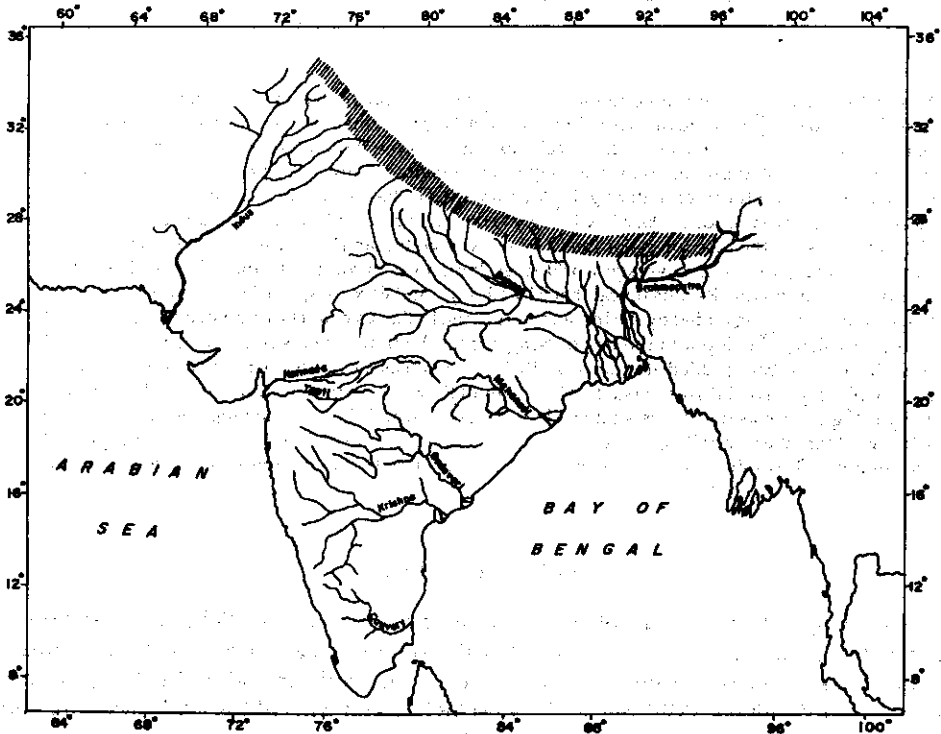


Fig. 1. Major rivers flowing into the northern Indian Ocean.

Table 1. Total bed load and denudation rates for the Indian Rivers

	Chemical	Sediment	Total
Load (10^9 kg yr^{-1})	282	1209	1491
Denudation rate ($10^4 \text{ kg km}^{-2} \text{ yr}^{-1}$)	8.21	32.7	40.9

Modified from SUBRAMANIAN (1979)

Rivers carry substances in forms of dissolved and suspended loads. SUBRAMANIAN and DALAVI (1978) found that Indian rivers in mountainous terrain carry higher amounts of suspended load whereas those in plain areas carry dissolved loads predominantly. Variations in mineralogy of the particulate material have been noticed depending on the nature of the catchment area (SUBRAMANIAN, 1980). For instance, suspended matter of the Ganges - Brahmaputra system consists mostly of chlorite, illite and kaolinite minerals while southern riverine solid load consists of montmorillonite as the dominant component. Sediment load of the Indian rivers is nearly four times greater than dissolved load in

Table 2. Major element fluxes (10^{10} g Y^{-1}) into the Bay of Bengal

Element	Discharge ($\text{m}^3 \text{ Y}^{-1}$)	39.3×10^{10} Ganges	60.9×10^{10} Brahmaputra	10.5×10^{10} Godavari	6.8×10^{10} Krishna	6.7×10^{10} Mahanadi	2.1×10^{10} Cauvery	Total
Na ⁺	395.6	128.8	182.0	234.0	68.0	468.3	1477	
K ⁺	105.6	113.4	27.0	18.0	10.0	44.1	318	
Ca ²⁺	998.0	857.7	274.0	136.0	70.0	483.0	2819	
Mg ²⁺	274.7	233.4	64.0	52.0	64.0	77.7	766	
Cl ⁻	195.0	67.4	153.0	176.0	98.0	199.5	889	
SO ₄ ²⁻	336.0	614.4	409.0	211.0	210.0	63.0	1543	
HCO ₃ ⁻	4995.9	3556.3	1380.0	977.0	410.0	294.0	11613	
SiO ₄ ⁴⁻	324.4	474.0	230.0	95.0	6.0	38.1	1167	
TDS	7 626.0	6045.0	2436.0	1911.0	1039.0	668.0	20725	

* UNESCO (1971) - 12 year average discharge (for the period 1949-60) at Farakka.

** Discharge data from SARIN et al. (1989)

*** Ionic data from MEYBECK (1979); Ionic data from SARIN et al. (1989)

**** Ionic data from RAMANATHAN et al. (1988)

Ionic data from SUBRAMANIAN (1979) for the rest of the rivers

Table 3. Major element fluxes (10^{10} g Y^{-1}) into the Arabian Sea

Element	Discharge ($\text{m}^3 \text{ Y}^{-1}$)	23.8×10^{10} Indus	4.71×10^{10} Narmada	1.8×10^{10} Tapti	Total
Na ⁺	213.9	36.6	51.2	302	
K ⁺	46.9	26.9	5.8	80	
Ca ²⁺	629.3	69.2	5.1	703	
Mg ²⁺	133.7	55.5	23.7	209	
Cl ⁻	170.2	122.1	36.5	329	
SO ₄ ²⁻	624.0	87.1	55.8	767	
HCO ₃ ⁻	2135.0	441.3	311.2	2987	
SiO ₄ ⁴⁻	120.0	73.0	38.0	231	
TDS	4073.0	901.9	528.6	5503	

* Discharge from MEYBECK (1979), Ionic data from SUBRAMANIAN (1979)

agreement with the denudation rates (Table 1). This is due to the dominance of the Ganges, Brahmaputra and Indus rivers discharges. Since these three rivers rise from the Himalayas and other mountainous regions, they drain higher quantities of suspended load (SUBRAMANIAN, 1978). The world's highest erosion rate occur in the Himalayas, pertaining to the Ganges-Brahmaputra drainage basins. With the observed denudation rates, SUBRAMANIAN (1978) predicted the mean elevation of the Indian subcontinent to be reduced to the present mean sea level in the next five million years time. Indian subcontinent occupies 7% of the global area and accounts for about 6% of the global mass transfer across the land - ocean boundary (SUBRAMANIAN, 1979).

Total dissolved solids and major ions

Based on the works of LIVINGSTONE (1963) and MEYBECK (1979), it is estimated that the concentration of total dissolved solids (TDS) carried by rivers of the Indian, Atlantic, Arctic and Pacific oceanic areas are 155, 79, 124 and 105 mg dm⁻³, respectively (MARTIN and WHITFIELD, 1983). These clearly reflect the higher TDS in river water of the Indian Ocean region compared to other oceanic areas. SUBRAMANIAN (1979) found a TDS concentration of the same magnitude (159 mg dm⁻³) for the average Indian river water and also deduced that this water is alkaline besides having the TDS higher by 25% of the global average river. Six major rivers drain into the Bay of Bengal and three into the Arabian Sea, whose major ionic compositions are given in Tables 2 and 3, respectively. The concentrations reveal in general that the major ion contents are inversely proportional to the runoff, with few exceptions, which is in concurrence with the finding of MEYBECK (1979) for major world rivers. This is more so for the rivers draining into the Arabian Sea than into the Bay of Bengal. A recent work by CHAKRAPANI and SUBRAMANIAN (1990) reports slightly higher concentrations of dissolved constituents in the Mahanadi than those considered here, but the flux differences are not significant considering the magnitude of variabilities involved. There does not appear to be a definite correlation between the TDS and discharge rates although the TDS is generally high at low values of discharge rates (Fig. 3). This is against the positive relationship observed between river discharge and TDS by MEYBECK (1979) for the major rivers of the world. Among the major ions in Tables 2 and 3, silica is found to behave nonconservatively in the Godavari with a loss of about 11% (BOROLE et al., 1977; SARIN et al., 1985) and in the Ganges the loss is between -3 and 33% (SEN GUPTA et al., 1989). Hence, in the flux evaluation an average of 10% silica removal in Indian estuaries was assumed and silica fluxes are given accordingly (Table 2 and 3).

Table 4. Dissolved major element fluxes (10¹² g Y⁻¹) to the northern Indian and World Oceans

Element	N Indian Ocean	World Ocean
Na ⁺	17.8	198.2
K ⁺	4.0	56.1
Ca ²⁺	35.2	497.4
Mg ²⁺	9.8	115.9
Cl ⁻	12.2	224.4
SO ₄ ²⁻	23.1	325.4
HCO ₃ ⁻	145.0	1933.6
SiO ₄ ⁴⁻	14.0	400.2
TDS	262.3	3799.8

Fluxes of major ions and TDS to the Bay of Bengal and the Arabian Sea are also shown in Tables 2 and 3, respectively. The Bay of Bengal receives four times more

TDS than the Arabian Sea, which is also the case with most of the major ions. Table 4 lists major ions and TDS fluxes into the Indian (from Table 2 and 3) and World Oceans (MARTIN and WHITFIELD, 1983). In this evaluation, discharges from minor rivers amounting to 3000 m³/sec (RAO, 1975) was also included. It is obvious from Table 4 that the Indian rivers are enriched in all the major ions except Na, compared to the global average. Lower TDS in the world rivers compared to the Indian rivers reveals the significant contributions from the Indian rivers to the World Oceans mass balance (Table 4) and the quantity added is about 6.7% of the world ocean's influx annually. Studies by BOROLE et al.(1979), RAY et al.(1984) and SARIN et al. (1985) in Mahanadi, Godavari and Krishna estuaries established the conservative behaviour for major cations. Hence, it could be concluded that the major ion fluxes given in Tables 2-4 are fluxes to the Indian Ocean, since these are least affected by estuarine processes, except Si as mentioned earlier.

Nutrients and uranium

Concentrations of nutrients such as phosphate and nitrate are known only for a few rivers (Table 5).The Ganges and Mahanadi river waters have higher phosphate concentrations, whereas the Ganges, Narmada and Vellar rivers have high nitrate concentrations. However, compared to fluxes from major rivers, contribution of phosphate and nitrate fluxes from minor rivers are insignificant (Table 5). Table 5 also includes available ²³⁸U concentrations for and fluxes from some rivers. Higher concentrations were observed in Krishna river water ranging between 1.23 and 1.93 dpm dm⁻³ (SARIN et al., 1985). During estuarine mixing ²³⁸U behaves conservatively in the Mahanadi, Godavari and Tapti estuaries (BOROLE et al., 1977; 1979; SARIN et al., 1985) but behaves nonconservatively in Narmada (BOROLE et al., 1982a) and in Krishna (SARIN et al., 1985) estuaries. Using the 0.19 dpm dm⁻³ at a chlorosity of 0.10 g dm⁻³ in Narmada estuary, the percentage removal of uranium with respect to its concentration at 0.04 g dm⁻³ chlorosity (0.72 dpm dm⁻³, BOROLE et al., 1982 a) is about 26. Hence, by using this value for Narmada estuary and not considering ²³⁸U flux from Krishna river, in view of its removal in higher quantities (SARIN et al., 1985), the estimated ²³⁸U input to the Indian Ocean through the Indian rivers is about 1200 x 10⁶ g y⁻¹. The dissolved uranium addition is 1175 x 10⁶ g y⁻¹ to the Bay of Bengal whereas the amount added to the Arabian Sea is only about 2% of the total dissolved uranium added to the northern Indian ocean. However, for the total uranium flux (dissolved plus suspended) to the Indian Ocean, a conservative estimate based on the data of BIKSHAM and SUBRAMANIAN (1988) and SARIN et al. (1990) is 8.2 x 10⁹ g y⁻¹. Recent data of SARIN et al. (1990) show dissolved ²²⁶Ra flux to the Bay of Bengal to be about 90 x 10¹² dpm y⁻¹ which equals to about 41 g y⁻¹ whereas the total flux from the Ganges-Brahmaputra system is 2.7 x 10³ g Y⁻¹.

Organic carbon

Recently, ITTEKKOT et al. (1985) and ITTEKKOT and ARAIN (1986) reported the concentrations of various components of organic carbon (dissolved and particulate) from the Ganges and the Indus rivers, respectively. The Indus river water contains higher DOC than that of the Ganges, but the individual fluxes from both the rivers to ocean do not vary significantly (Table 6) because of the low freshwater discharge from the Indus (Fig. 2). SHOLKOVITZ (1976) found a removal of 3-10% DOC during estuarine mixing in laboratory experiments. Since a part of the incoming DOC will be used in estuarine biological production, a maximum removal of about 20% riverine DOC is considered for the flux evaluation given in Table 6. By assuming an average Indian river DOC concentration of 2.53 mg dm⁻³, representing the Ganges water, DOC concentration after removal, and with a total runoff of 156 x 10¹⁰ m³ yr⁻¹, the estimated

DOC input to the Indian Ocean is 3.95×10^{12} g yr⁻¹ (Table 6). Data show that the POC concentration are similar in both the Indus and the Ganges rivers (ITTEKKOT et al., 1985; ITTEKKOT and ARAIN, 1986) except during March and May when very high concentrations of POC (~ 5%) are observed in the Ganges (ITTEKKOT et al., 1985). However, during the monsoon months, when the river runoff is at its maximum, low (0.7-1.25%) POC was observed in both the rivers. Excluding 30% of the riverine POC for its degradation potential (ITTEKKOT and ARAIN, 1986), and 90% of the remaining POC for its possible removal in the upper reaches and estuaries, the net POC fluxes are computed (Table 6). In this regard a total sediment load of 2.873×10^{12} kg yr⁻¹ (MILLIMAN and MEADE, 1983) was used, for POC flux from the Indian subcontinent. The total dissolved carbon fluxes show that DOC flux is higher than POC (Table 6). The calculated flux of 12.25×10^{12} g yr⁻¹ by ITTEKKOT and ARAIN (1986) is higher than 1.41×10^{12} g Yr⁻¹ (Table 6) because the former study did not consider POC removal in estuaries.

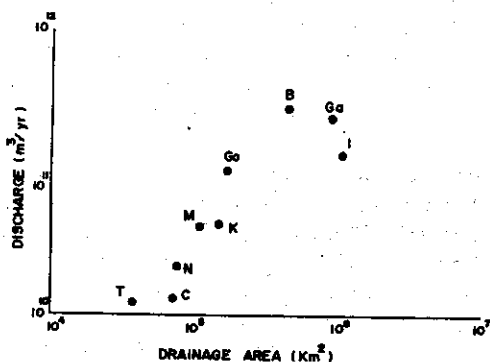


Fig. 2. Relation between freshwater discharge and drainage area of the major rivers on the subcontinent.

Table 5. Fluxes (10^6 g y⁻¹) of dissolved inorganic nutrients, Uranium and Radium to the northern Indian Ocean

River	Phosphate	Nitrate	Uranium (10^6 g Y ⁻¹)	²²⁶ Ra (10^{10} dpm y ⁻¹)
Ganges ^a	45981	51090	711	2750
Mahanadi ^b	3900	1600	17	-
Godavari ^c	-	-	65	420
Narmada ^c	1832	8547	21	-
Krishna ^d	-	-	78	340
Vellar ^e	5.1	34	-	-
Mandovi ^f	0.61	0.9	-	-
Zuari ^f	0.21	0.76	-	-
Cauvery ^g	17220	-	-	-
Brahmaputra ^h	-	-	384	5480
Tapti ^h	-	-	4	-
TOTAL	51719	61272	1280	89.9

^aSEN GUPTA et al. (1989) and SARIN et al. (1990); ^bNIO (1986) and SEN GUPTA and UPADHYAY (1987); ^cBOROLE et al. (1977) and ZINGDE et al. (1981); ^dSARIN et al. (1985); ^eRAJENDRAN (1974); ^fDE SOUZA (1983); ^gRAMANATHAN et al. (1988) and ^hSARIN et al. (1990).

DISCUSSION

The flux evaluations for various dissolved substances (Table 2-6) reveal that the major ions contribute more than 95% of the total mass transfer to the Indian Ocean from the subcontinent (Table 7). The present estimation revealed that the total inputs, including both dissolved and suspended loads, of Na, K, Mg, Ca and Si (major elements) to the Indian Ocean from the Indian rivers are 21.0, 9.7, 13.6, 45.0 and 22.0 $\times 10^{12}$ g y^{-1} , respectively. Here, suspended load concentration of those elements are taken, on an average, as that of Ganges particulate composition (MARTIN and MEYBECK, 1983). Contributions from nutrients and organic carbon to the total flux are minor.

Table 6. Fluxes^a (10^{12} gC Y^{-1}) of DOC and POC

River	DOC	POC
Ganges ^b	1.24	0.28
Indus ^c	2.08	0.10
TOTAL (all rivers)	3.95	1.41

^aafter assuming removal processes for POC and DOC
^bITTEKKOT et al. (1985) and ^cITTEKKOT and ARAIN (1986).

Table 7. Dissolved inputs into the Indian Ocean

Parameter	Input (10^{12} g y^{-1})
Major ions	262.3
Nutrients	0.11
DOC	3.95
Uranium	0.0013
TOTAL	266.3613

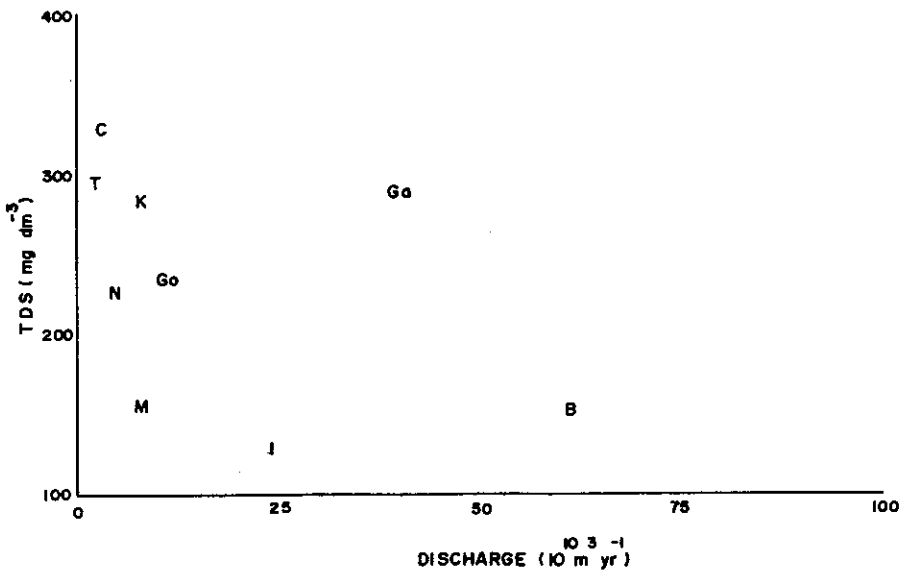


Fig. 3. Relationship between discharge and particulate material of major rivers.

Table 8. Particulate metal fluxes^a (10^{12} g Y⁻¹) to the northern Indian Ocean through rivers

Element	Narmada	Tapti	Ganges	Godavari	Krishna	Cauvery	Mahanadi	Total
Al	0.42	0.06	1.53	0.813	0.014	0.00019	0.012	2.85
Fe	0.38	0.063	1.70	0.72	0.019	0.034	0.08	3.00
Mn	0.0056	0.001	0.035	0.022	0.0003	0.0009	0.0007	0.066
Ni	0.00035	0.00005	0.005	0.005	0.00003	-	0.00001	0.006
Cu	0.00071	0.00011	0.002	0.001	0.00002	0.00002	0.00008	0.004
Zn	0.00063	0.00012	0.004	0.0006	0.00003	0.00006	0.00009	0.005

^aAfter assuming removal of river suspended matter in estuaries and upstream areas. Data for Narmada and Tapti are from BOROLE et al. (1982b) and for the rest of the rivers from CHAKRAPANI and SUBRAMANIAN (1990).

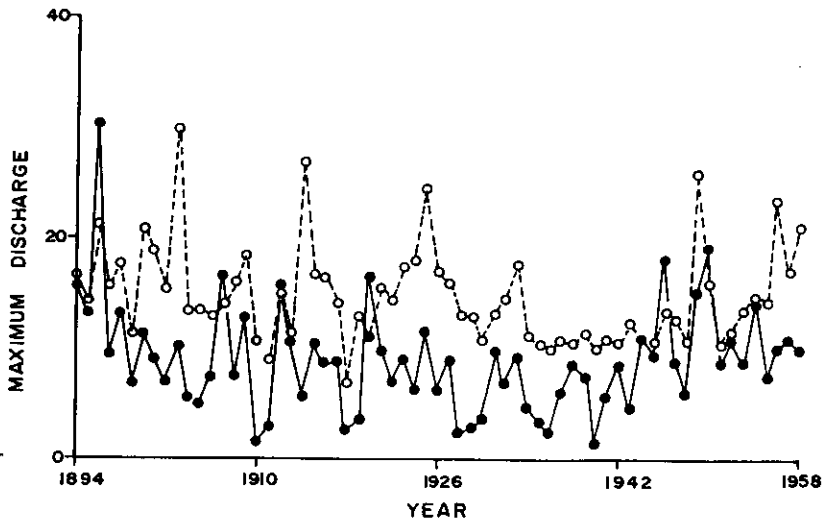


Fig. 4. Maximum discharge rates ($10^3 \text{m}^3 \text{S}^{-1}$) and maximum discharge volumes 10^9m^3 ; • during floods from 1894 to 1958 for the Krishna River.

In spite of the enormous amount of SPM carried by the Indian rivers, not much is known about its composition and nature. The studies available in this regard are those of MARTIN and MEYBECK (1979), ITTEKKOT et al. (1985) and NIO (1986) for Ganges particulates, BOROLE et al. (1979; 1982b) for the Narmada and the Tapti particulates, ITTEKKOT and ARAIN (1986) for the Indus particulates and SUBRAMANIAN et al. (1985), RAMESH and SUBRAMANIAN (1988), BIKSHAM and SUBRAMANIAN (1988) and CHAKRAPANI and SUBRAMANIAN (1990) for the rest of the rivers flowing into the Bay of Bengal. Table 8 depicts Al, Fe, Mn, Ni, Cu and Zn and suspended fluxes to the Arabian Sea and the Bay of Bengal. Here again Ganges and Godavari suspensoids transport larger quantities of metals.

The composition of the Narmada and Tapti particulates (BOROLE et al., 1982b) is almost similar to that of the Ganges particles (MARTIN and MEYBECK, 1979; NIO, 1986) excepting copper which has very low concentration in Ganges particulates. BOROLE et al. (1977; 1982b) observed no considerable change in the composition of river particles during their passage through estuaries, where adsorption-desorption reactions occur, and that particulate composition basically reflected the Narmada and the Tapti basement rocks. Although no significant variations occur for Al and Fe in suspended sediments of the rivers draining into the Bay of Bengal, there seem to be considerable variations (nearly five fold) for the rest of the elements in Table 8, as can be seen from CHAKRAPANI and SUBRAMANIAN (1990). Particulate metal fluxes from these rivers are calculated by assuming that a minimum of 10% of the SPM load reaches the sea (Table 8). Conspicuously, the rock forming elements Aluminium and Iron contribute to the maximum flux among the metals considered in Table 8.

Constraints

It may be conceded that the above estimates suffer from large uncertainties as there are many constraints involved in the observations and estimations of this kind. The potential errors arise mostly from the quality of data followed by the temporal and

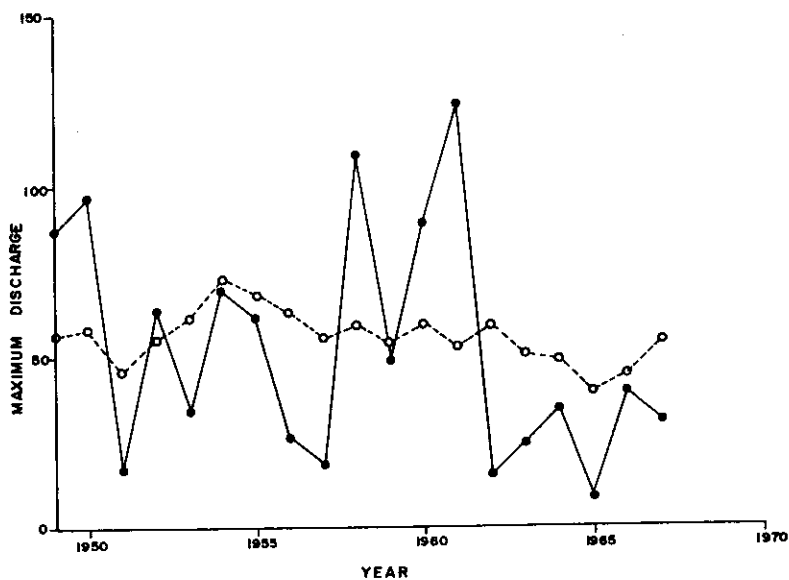


Fig. 5. Maximum discharge rates ($10^3 \text{ m}^3 \text{ s}^{-1}$) and maximum discharge volumes 10^9 m^3 ; • during floods from 1949 to 1957 for the Ganges River.

spatial variability in the composition as well as the volume transports. Another constraint that places extreme limitations is the periodic occurrence of floods in addition to that by tidal amplitudes on short time scale. Although these floods occur for brief periods, these result in enormous spontaneous transportation of materials to oceans while altering not only the normal course of the river but its topography as well. Even if one could make flux measurements during flood periods in an year, the same may not hold good every year due to the large variability of the floods. Figs 4 and 5 depict the annual variabilities in flood discharges for the rivers Krishna and Ganges for 64 years and 22 years, respectively based on data from UNESCO (1976). Figs 4 and 5 show maximum flood discharges found on 7 August 1896 for the Krishna ($3.02 \times 10^{10} \text{ m}^3 \text{ Y}^{-1}$) and 28 August, 1964 for the Mahanadi ($3.14 \times 10^{10} \text{ m}^3 \text{ y}^{-1}$). These flood discharges observed for a day or two (mostly less than a week) account for nearly half of the normal annual run off of these rivers. Uncertainties could also arise due to temporal variabilities in source run off, composition of source water (CIFUENTES et al., 1990) and sediment loads. A major problem with the quantification of sediment load is the representative suspended matter estimation (HOROWITZ et al., 1990). The surface water generally contains small sized particles but the size and abundance increase with depth. Hence, collection of suspended matter from one depth of the water column leads to erroneous result. HOROWITZ et al. (1990) documented significant spatial and temporal variations in riverine particulates abundance for selected riverine cross sections, based on data from time series and depth integrated sampling methods. Further, these authors reported significant increase in suspended sediments in water a day after a storm occurrence, with a substantial increase in suspended particulate matter fraction $< 63 \mu\text{m}$ and a decrease in the fraction $> 63 \mu\text{m}$. During this time, while Fe in $< 63 \mu\text{m}$ fraction remained at the same concentration, Cu, Zn and Pb showed increases of 2, 3 and >100 times, respectively. Another significant uncertainty arises from the variations in saline water incursion into estuaries with tidal variation. Collection of samples in an estuary during one full tidal cycle will not lead to accurate assessment of the elemental behaviour. Further, behaviour of elements in

the estuarine water with salinity less than 2×10^{-3} is significant (MORKIS et al., 1978) and has to be done before making conclusions. Using speed boat and covering this low salinity waters in similar tidal conditions, MORRIS et al. (1978) established the occurrence of significant variations in the concentrations of dissolved trace metals.

Suggestions for future work

Based on the constraints noted above we make the following suggestions in order to carry out future observations in a more comprehensive manner and to make reasonable estimates of material transport to the oceans from rivers. Involvement of several groups for the simultaneous collection of samples at different places from source region to the river mouth is required. A close monitoring on the quality of data is of prime importance. The aspects those need to be investigated are:

- a) Variabilities in river source composition and run off.
- b) Compositional changes of river water during the flow.
- c) Variabilities in suspended matter, through integrated sediment sampling and its composition.
- d) Variations in river topography and cross sections and their influence on material transport
- e) Estuarine mixing pattern, including the lateral circulation.
- f) Elemental behaviour in low salinity regions.
- g) Behaviour within the estuaries and the extent of removal or addition of materials
- h) Estimation of material fluxes from rivers to oceans through estuaries.

Acknowledgements - We thank the Director, NIO, for his kind encouragement.

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