AN ENVIRONMENTAL OUTLOOK OF THE HYDRO-GEOCHEMISTRY OF THE BRAHMAPUTRA RIVER SYSTEM

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ABSTRACT

The Brahmaputra is perhaps the most poorly studied large river of Asia. This is despite the fact that global estimate of river solute transport is incomplete without taking into account such a high sediment yielding river. Water, suspended and bed sediment samples collected from different locations over a stretch of about 750 km during monsoon and dry seasons were analysed for their elemental chemistry. The seasonal and spatial distribution of major elements over the basin was evaluated. The size distribution of the suspended sediments and the mineralogy of the suspended sediments were derived to find the percentages of different size fractions and that of detritals, carbonates and clay minerals. Average ion chemistry and sediment composition of the Brahmaputra river were compared with those of other major rivers of India.

The ion chemistry of the Brahmaputra is characterised by high bi-carbonate content and source rock influence. Sediment chemistry reveals abundance of Si and Al, and amongst the heavy metals, dominance of Fe, Mn, Zn and Cu. Suspended sediments vary in size from fine sand to clay. Quartz, Feldspar and clay minerals constitute 90% of the suspended sediment mineralogy. Sediment chemistry reveals marked difference between the Brahmaputra and the Ganges, with respect to HCO_3, SO_4 and Ca as well as Al, Fe and Zn.

1.0 INTRODUCTION

The bulk of the sediment discharge into the world ocean takes place through the rivers of Asia and the Pacific Islands (Milliman and Meade 1983). With about 70% contribution of the total global discharge, these rivers must be taken into account in any attempt of estimating river-transport on a global scale. However, despite their significant role in transport of water and sediments to the oceans, very few Asian rivers have been investigated in detail so far and the Brahmaputra is perhaps the least studied of them all. Only brief reports have appeared from time to time based on very few samples (often one or two) on the water chemistry (Subramanian 1979; Hu Ming-Hui and others 1982, Sarin and Krishnaswami 1984, Sarin and others 1989), sediment characteristics (Subramanian 1980, Goswami 1985) and heavy metal concentrations in sediments (Subramanian and others 1987). The present paper deals with the entire part of the basin lying within the geographical boundaries of India and incorporates seasonal and spatial variation for a number of parameters considered.

2.0 THE BRAHMAPUTRA RIVER BASIN

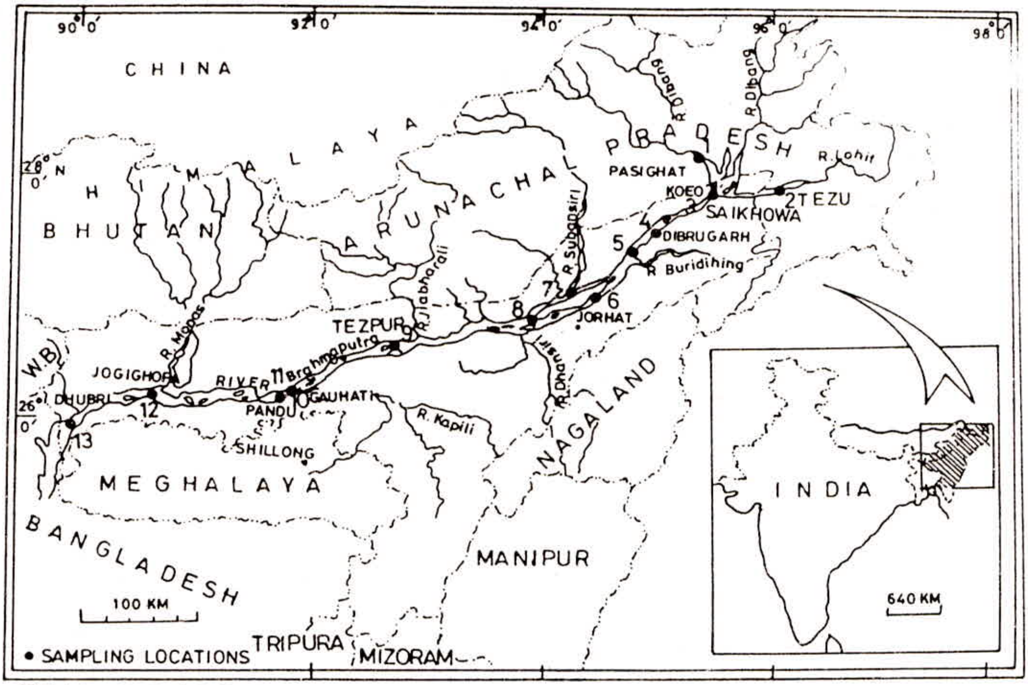
With a total length of about 2900 kms. and the drainage basin covering an area of 1.6×10^6 sq.km., the Brahmaputra is the fifth largest river in terms of average discharge at mouth, with a flow of 19,830 m^3s^{-1} (Goswami 1985). The main channel receives extensive sediment inputs from 42 major tributaries. Its average sediment load per unit drainage area (average annual suspended load at Pandu, Assam is more than 402 million tonnes. yr^{-1}) puts it next only to the Yellow river in China and the Magdalena river in Columbia (Goswami 1985).

The Brahmaputra is characterized by very high rates of basin erosion, high sediment yield and frequent channel changes (Goswami 1988). Little information is available on the geology of the Tibetan Himalayas where the river has originated. Hu Ming-Hui and others (1982) have described the dominant lithology of this region to be of reduced shales, gneisses, carbonates and perhaps some volcanic rocks at a few places. Inside India, while the upper reaches of the river basin predominantly drain the Siwalik sediments including limestones, dolomites and calcareous shales, the drainage lithology downstream is composed of gneisses and schists of the Precambrian age (Fig. 1A). The Brahmaputra valley in Assam is underlain by 200-300 m thick recent alluvium. Oldham (1900), Evans (1964) and many other authors have suggested a tectonic origin of the Brahmaputra basin.

3.0 MATERIALS AND METHODS

Water samples were collected from the main channel during June-July 1993 and January-February 1994. Sampling locations are shown in Fig. 1B. Altogether twenty six samples of water were collected in 1 litre and 5 litres wide mouth polyethylene bottles along the middle part of the river by holding the bottles against the flow at about mid-depth. Due to non-availability of depth integrated sampler, this sampling technique was adopted. Considering the great width but comparatively shallow depth of the river, it is however difficult to obtain a true representative sample, as complete lateral mixing of tributary inputs (which is significant) may not have taken place at each sampling site.

Suspended sediments were derived from 5 litres composite water samples by settling and decanting. Water samples for analysis of major ion chemistry were obtained by filtering the 1 litre samples through 0.45 μm Millipore membrane filters. 13 bed sediment samples were collected during June-July 1993 from the same locations by scooping freshly deposited materials with a plastic spade. The materials were transferred to plastic bags taking care not to lose the fines. After measuring pH, EC and alkalinity of the water samples in the field, all the water, bed and suspended sediment samples were kept refrigerated at 2° to 4°C until they were processed for laboratory analyses.



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DIBRUGARH
R. Buridihing
R. Subansiri
R. Jiabharali
JORHAT
TEZPUR
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Brahmaputra
RIVER
JOGIGHOPA
DHUBRI
PANDU
GAUHATI
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SHILLONG
R. Kapili
R. Dhansiri
NAGALAND
MEGHALAYA
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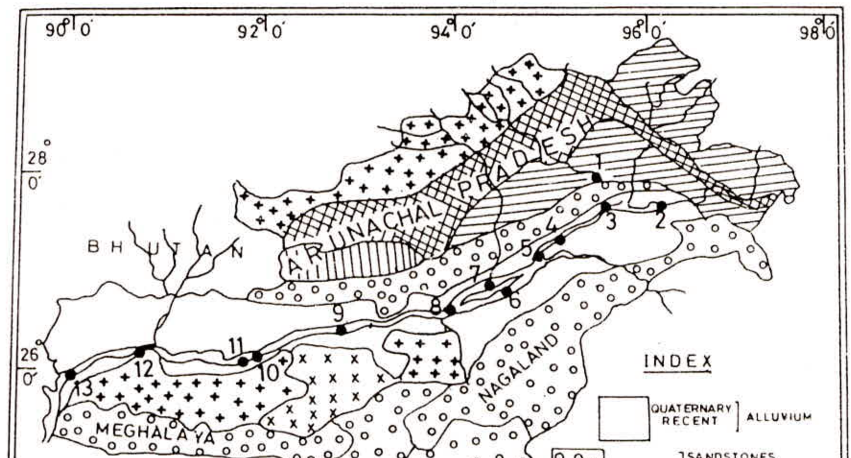
• SAMPLING LOCATIONS
INDIA
640 KM

Fig. 1 A



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INDEX
QUATERNARY RECENT ALLUVIUM
TERTIARY SANDSTONES SHALES LIMESTONE
UPPER PALAEOZOIC SANDSTONES SHALES
LOWER PALAEOZOIC SCHISTS QUARTZITES
UPPER PROTEROZOIC SCHISTS PHYLLITES SLATE QUARTZITES
LOWER PROTEROZOIC GRANITES GNEISSES
ARCHAEAN GNEISSES SCHISTS GRANITES

Fig. 1 B

Standard analytical procedures were adopted for water analyses (Cl^- by Mohr's titration, F^- by Corning pH ion meter, SO_4^{2-} by Barium perchlorate titration and phosphate and silicate by calorimetric technique, using a Cecil double beam spectrophotometer). Ca^{2+} and Mg^{2+} were analysed in absorption mode and Na^+ and K^+ in emmission mode, using an atomic absorption spectrophotometer (GBC 901). SiO_2 and Al_2O_3 in suspended and bed sediments were analysed by preparing "solution A" (Shapiro and Brannock 1962). Other cations in the suspended and bed sediments were determined by AAS after their complete digestion (by adding 0.5 ml of HNO_3, 1.5 ml of HCL and 5 ml HF to 0.1 g of sediment and keeping the mixtures in a teflon bomb inside an oven at 100°C for 90 minutes) to solution form. Accuracy and precision of the measurements were checked by comparing with values obtained for various USGS rock standards (MAG-1, SCO-1,SDC-1,G-2) (Flanagan 1976). Slides of suspended sediments were prepared by drop-on-slide technique (Gibbs 1967). After being glycolated they were run on a Philips X-ray diffractometer with Cu-Kα radiation using Ni filter. Mineral identification and estimation of their abundance were done by the methods of Biscaye (1965) and Carrol (1970). Grain size distribution in the suspended sediments, was determined by a FRITSCH Analysette-22 laser based Particle Size Analyser.

4.0 RESULTS AND DISCUSSION

Table 1 shows the results of the water analyses. With $_pH$ averaging 7.5, the water of the Brahmaputra is slightly alkaline. The Brahmaputra does not show much seasonal or spatial change in pH EC during monsoon ranges between 121 $\mu s.cm^{-1}$ 139 $\mu s.cm^{-1}$ while it is 139 $\mu s.cm^{-1}$ to 172 $\mu s.cm^{-1}$ during the low flow period of winter. Correspondingly, the ionic strength increases from about 0.002 to 0.003 during dry season indicating an increased concentration of major ions due to evaporation and influence of groundwater.

Cl^{-1} values in winter are consistently higher relative to those during monsoon which suggests a dilution effect during high discharge period. Higher Cl^{-1} values during non-monsoon may also represent enrichment from the reported salt (halite) deposits of the upper Tibetan reaches of the Brahmaputra (Hu Ming-Hui and others 1982). This is further supported by a similar trend shown by Na values. Bicarbonate is generally high in Brahmaputra. Both carbonate dissolution as well as primary and secondary mineral weathering are the source of HCO_3. Following Raymahasay's (1987) method, it has been calculated that on an about average, 40% bicarbonates in the water of the Brahmaputra comes from the carbonate minerals of the basin and the rest from the silicates. Based on the HCO_3 content and pH, the P_{co2} values calculated for the Brahmaputra lie between 10^{-2} to $10^{-3.5}$ atm. which supports the global trend that rivers are not in equilibrium with the atmosphere.

Sulphate concentration (Avg. 3.8 ppm) is lower than the average for Indian rivers (13 ppm : Subramanian 1987). Oxidation of pyritic sediments (Gansser 1964) and Gypsum or anhydrites may have major contribution to sulphates. This is indicated by SO_4 having good correlation with Calcium. The average dissolved silica concentration for Brahmaputra is 8 ppm, little higher than

Table 1 : Chemical Composition of water of the Brahmaputra river
(Units : $mg.l^{-1}$, except p^H and cond; Conductivity in $\mu S.cm^{-1}$)

Sample No.	Sampling period	p^H	EC	Cl^-	HCO_3^{-1}	SO_4^{-2}	PO_4^{3-}	F^-	H_4SiO_4	Na^+	K^+	Ca^{2+}	Mg^{2+}	TDS	dE^-	dE^+	TSM
1	m	7.6	124	4	54	2.3	0.09	0.2	8	2	1	12	5	89	1.06	1.12	135
	d	7.2	139	13	48	3.6	0.07	0.1	4	8	2	14	5	98	1.30	1.51	5
2	m	7.7	124	4	57	1.5	0.05	0.1	11	2	2	14	4	87	1.08	1.17	124
	d	7.6	156	19	52	3.9	0.06	0.1	5	7	3	16	5	111	1.47	1.59	60
3	m	7.7	121	6	53	1.7	0.05	0.1	10	2	2	12	5	92	1.08	1.15	185
	d	7.5	152	19	49	3.7	0.08	0.1	6	8	3	15	5	109	1.43	1.60	31
4	m	7.3	138	5	61	2.0	0.06	0.1	9	3	2	16	5	103	1.19	1.39	178
	d	7.8	172	23	55	3.4	0.04	0.1	5	8	3	16	6	120	1.48	1.71	35
5	m	7.3	126	4	61	1.8	0.04	0.1	9	2	1	17	4	100	1.15	2.29	492
	d	7.6	168	19	54	4.9	0.04	0.1	6	10	3	18	6	121	1.52	1.60	66
6	m	7.8	130	5	59	2.4	0.07	0.1	12	4	3	13	5	104	1.16	1.31	427
	d	7.8	169	18	56	4.8	0.05	0.1	6	12	2	15	6	120	1.50	1.80	19
7	m	7.3	117	5	56	1.8	0.07	0.1	10	2	2	12	4	93	1.10	1.07	391
	d	7.3	164	17	54	5.2	0.05	0.1	6	14	4	14	4	118	1.35	1.75	29
8	m	7.5	139	4	61	2.6	0.07	0.1	7	2	2	15	4	98	1.12	.22	468
	d	7.4	166	11	58	5.3	0.06	0.1	6	15	3	16	4	118	1.37	1.86	21
9	m	7.3	126	5	54	1.6	0.12	0.2	9	2	2	12	4	90	1.07	1.02	960
	d	7.4	160	13	52	7.0	0.06	0.1	6	14	4	14	4	114	1.38	1.74	90
10	m	7.5	119	5	58	2.0	0.10	0.2	8	2	3	14	4	96	1.14	1.19	820
	d	7.4	168	13	56	7.5	0.07	0.1	6	14	4	14	5	120	1.44	1.80	40
11	m	7.5	139	5	61	2.1	0.14	0.2	9	5	3	17	3	105	1.20	1.44	790
	d	7.8	170	15	59	7.2	0.06	0.1	7	11	2	17	4	122	1.54	1.71	30
12	m	7.4	124	5	53	1.9	0.16	0.2	11	2	3	12	4	92	1.11	1.09	660
	d	7.8	151	15	51	5.4	0.07	0.1	8	11	2	12	5	110	1.30	1.54	20
13	m	7.7	127	6	62	2.0	0.18	0.2	11	2	3	14	3	103	1.24	1.11	1500
	d	7.9	169	15	58	9.0	0.07	0.1	7	12	2	15	4	123	1.52	1.68	30

m : *monsoon (June-July '92)*
d : *non monsoon (Jan-'94-Feb-'94)*
E^+ and E^- : *Ionic balance in miliequivalents/ltr.*

the Indian average (7 ppm, Subramanian and others 1987) but less than the world average (10.4 ppm; Martin and Meybeck 1979). Due to extensive draining of the catchment area by heavy rains (of the order of 1650 mm from June to September against about 60 mm during December to January), dissolved silica is higher during monsoon. Weathering of carbonates, sulphates and silicates releases most of the Ca in the Brahmaputra. Mg is released from dissolution of dolomitic rocks and also likely from some volcanic rocks reported (Sarin and others 1989) in the source area. Na shows greater mobility and pronounced seasonal variation than K in the Brahmaputra basin.

The results of the analysis of the single water sample collected from Brahmaputra by Hu Ming-Hui and others (1982) are similar to the present values obtained from the same station (both collected during monsoon) except for Mg. The values obtained by Sarin and others (1989) from three different stations fall outside the range of the present results with respect to HCO_3^-, Cl^- (present values are higher) and Mg^{++} (present values are lower). Samples by these authors were however, collected during April '82 and Dec '82 and the sampling seasons were different from those of the present study.

5.0 SUSPENDED SEDIMENT SIZE AND MINERALOGY

Suspended sediments range from fine sand to clay with mean size of 9 μm (Table 2). Size analysis indicates that the fraction greater than 12 μm constitutes the important size population of the suspended load. Dominance of detritals increases with the increasing grainsize of the suspended sediments (Table 3 A).

Upstream, higher size fraction ranging from 17 μm to 34 μm are dominant and towards extreme downstream, most of the suspended sediments are of size less than 17 μm. Within the silt fraction, distribution of different size populations vary spatially but does not show any trend. Along downstream, percentage of finer materials increases in the suspended sediments compared to upstream. (Table 2). These suspended sediments of Brahmaputra are moderately to poorly sorted (S.D=0.83 to 1.43) (Table 4). Positive to very positive skewness of the suspended sediments suggests that amount of finer material is more in the distribution. However, since these suspended sediments were collected during low flow and from shallow depths, the possibility that the present samples may not represent the total sand fraction in suspension, cannot be ruled out. The suspended load in a dynamic river like the Brahmaputra is expected to include particles of larger size than what was observed. An improved sampling technique too may provide better results.

Table 3A summarises mineral abundance in the suspended load of Brahmaputra. Suspended sediments are dominated by quartz, feldspar and clay minerals. Basin geology is the main controlling factor in the mineral distribution. However, in an actively degrading river system such as the Brahmaputra, the mineral composition of the sediments is controlled, to a considerable extent, by the composition of the local sediment sources as well as by continuous addition of detritus from bank cuttings. Quartz and Feldspar are present as detritals, mainly derived from the Pre-cambrian granite and gneisses. The river is characterised by the presence of significant amount of illite followed by almost equal amounts of chlorite (measured at 4.72A°; Biscaye 1965) and Kaolinite (7A°). Very little or no mixed layer clays or montmorillonites were not detected.

Table 2. Grain Size distribution of suspended sediments in the Brahmaputra river (In %)

Size class (micron)			Frequency (%)										
Low	Average	High	Loc.1	Loc.3	Loc.2	Loc.4	Loc.6	Loc.8	Loc.9	Loc.10	Loc.11	Loc.12	Loc.13
0.4	1.2	2	5	6	3	5	6	8	17	10	11	21	17
2	3	4	5	7	4	7	7	10	18	10	11	20	17
4	6.5	9	7	12	7	13	15	18	32	18	18	33	29
9	13	17	15	13	10	16	22	23	33	19	21	26	32
17	26	35	68	62	76	59	50	41	-	43	39	-	5

Table 3A : Semi-quantitative estimate of the minerals in the suspended sediments (bulk) (in %)

Loc. No.	Quartz	Feldspar	Carbonates	Clay minerals
1	41	39	4	16
2	43	29	-	28
3	42	27	9	32
4	53	37	-	10
5	63	14	4	19
6	53	13	2	32
7	61	10	15	14
8	36	20	14	30
9	44	19	6	31
10	33	15	3	49
11	42	18	2	38
12	45	14	8	43
13	32	10	5	53

Table 3 B : Percentage of clay minerals (weighted peak area %) in the suspended sediments (<2u)

Loc. No.	Chlorite	Illite	Kaolinite	Montmorillonite
1	22	59	19	-
2	36	25	39	-
3	25	47	28	-
4	21	61	18	-
5	17	61	13	9
6	20	64	16	-
7	34	39	27	-
8	32	38	28	2
9	35	40	25	-
10	36	27	35	2
11	42	25	33	-
12	45	18	37	-
13	36	21	31	2

observed in the suspended load. Unlike the peninsular rivers, chlorite is a dominant clay mineral in the Brahmaputra basin (Table 3B). However, this mineralogy characterises the suspended sediments much upstream the river mouth and may not represent exactly the final material transferred to the oceans after estuarine mixing. Mallick (1976) observed illite and kaolinite in the mouth of the Ganges-Brahmaputra with chlorite being abundant in individual samples, whereas Murthy and Srivastava (1979) found illite and quartz to be dominant in these samples.

Present study shows that in Brahmaputra, detrital contribution in the form of quartz, feldspar and mica make up more than 80% of the suspended sediments upstream. Then it gradually decreases downstream. Clay minerals, on the other hand, show an increasing trend (Table 3A) as the river flows down. Chlorite, illite and kaolinite form more than 95% of the total clay minerals. Illite being much more dominant in the upstream, suggests their primary origin to be from the granitic and metamorphic source rocks as a result of pre-dominant physical weathering in a cold and dry climate of the Tibetan Plateau.

Table 4 : Statistical parameters of suspended sediments size distribution (unit in phi)

Location No.	Mean	Stand. Deviation	Skewness	Kurtosis
1	5.91	1.10	0.74	1.47
2	6.33	1.31	0.85	2.44
3	5.83	0.83	0.73	4.37
4	6.20	1.19	0.75	0.94
5	6.63	1.28	0.17	0.98
6	6.67	1.38	0.26	0.84
7	7.70	1.10	0.32	0.68
8	6.73	1.43	0.74	1.47
9	6.73	1.43	0.26	1.80
10	6.77	1.41	0.25	0.75
11	7.93	1.21	0.20	0.80
12	7.77	1.27	0.30	0.82
1	5.91	1.10	0.74	1.47

6.0 SEDIMENT CHEMISTRY

The results of the chemical analyses of bed and suspended sediments have been plotted in Figure 2. Since the chemical data on the source rocks were not available, the sediment chemistry was compared with the average composition of surficial rocks exposed to weathering. The abundance and the relative mobility of the analysed elements in Brahmaputra are of the following order :

Bed sediments

Si>Al>Fe>Ca>Mg>Na>K>P>Mn>Zn>Cu>Cr>Pb>Cd

Suspended sediments

Si>Al>Fe>Na>K>Ca>Mg>P>Mn>Zn>Cu>Cr>Pb>Cd

Except in the cases of Si, Al, Ca, Na and Mg, the suspended sediments are more enriched in the remaining elements relative to the bed sediments. The enrichment factor in bulk suspended sediments relative to the bed sediments are 1.3 for Fe, 1.8 for Pb, 1.6 for Cu, 1.6 for Cr, 1.2 for Zn, 1.4 for Mn and 1.3 for Cd. This is generally attributed to the relative fineness of the suspensions and their richness in multiple hydroxide coatings, organic matters and trace metal scavenging clays (Foerstner and Wittman 1981). The bed sediment samples show 1.3 times more Si than the world average sediments (Si=28.5%), Brahmaputra Mean Si=36%) of Martin and Meybeck (1979). The basin, comprised mainly of granite, gneiss and sandstone terrains, undergoes extensive weathering under the influence of a wet humid climate in the downstream region. So the large number of tributaries drain a great amount of silicate minerals.

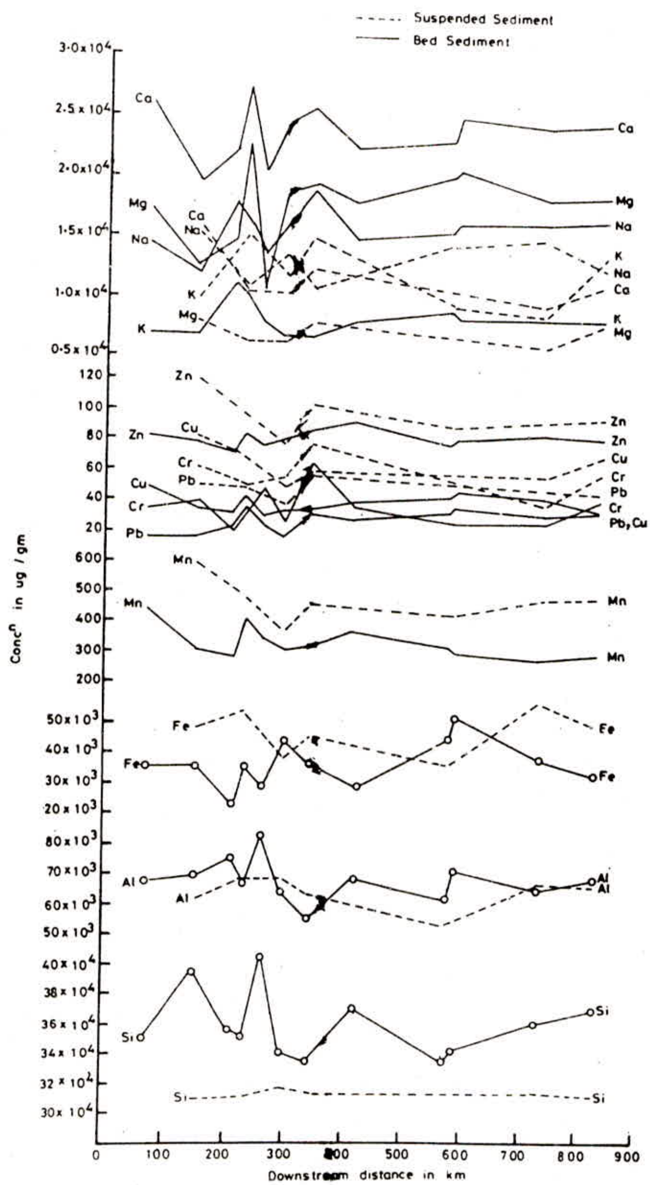

Fig. 2

No significant spatial variation was noticed in the concentrations of heavy metals both in the suspended and bed load (Fig. 2). Amongst the heavy metals Cu, Pb, Zn and Mn show good correlation with each other (Table 5) in the suspended sediments indicating their common source and identical mobility. Such a trend was not observed in the bed sediments. Figure 3 shows the metal/Aluminium ratios for the bed and suspended sediments in Brahmaputra. Since the ratio minimises the grain size effect on the heavy metals (Al being a conservative element), it gives a fairly good idea of the mobility of the heavy metals in the riverine environment (Bruland and others 1974). The relative mobility of the metals in the bed as well as suspended sediments of Brahmaputra are as follows:

Fe>Mn>Zn>Cu>Cr>Pb

The spatial variation in metal/Al ratios is irregular due to continuous addition of freshly eroded materials by a large number of tributaries at different points.

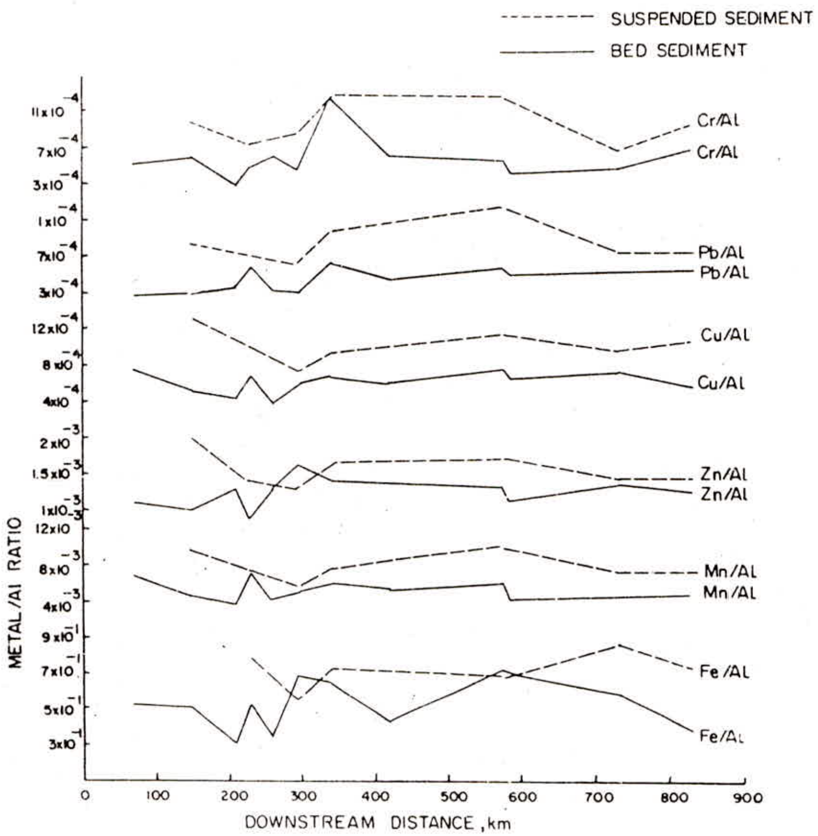

Fig. 3

7.0 CONCLUSION

The ion chemistry of the Brahmaputra is characterised by high bi-carbonate content and source rock influence. While higher values of TSM than TDS during monsoon indicate predominance of physical weathering over chemical weathering, during dry season, chemical weathering is relatively more pronounced. On an average 60% of the bicarbonates in the water of the Brahmaputra comes from silicate weathering and the rest from the carbonates.

Table 5 : Correlation matrix for the suspended sediments of the Brahmaputra river basin.

Element	Si	Fe	Al	Ca	Mg	Na	K	Cu	Zn	Pb	Cr	Mn	Cd
Si	--												
Fe	-.24	--											
Al	.35	.59	--										
Ca	-.46	-.06	-.07	--									
Mg	-.50	-.12	-.12	.75	--								
Na	.03	-.14	-.34	.26	-.12	--							
K	.29	.15	.42	-.02	.31	-.96	--						
Cu	-.80	.44	.11	.72	.54	.14	.07	--					
Zn	-.70	.40	.02	.84	.66	.10	-.09	.84	--				
Pb	-.60	.09	-.37	.44	.64	-.31	.32	.33	.66	--			
Cr	-.08	-.35	-.03	.56	.82	-.40	.52	.09	.38	.60	--		
Mn	-.74	.57	.10	.70	.51	.24	-.07	.94	.92	.43	-.47--		
Cd	-.80	-.06	-.38	.53	.25	.04	.06	.67	.54	.38	.04	.53	--

Table 6A : Average chemical composition of Indian rivers (in mg/l).

River	HCO_3	Cl	SO_4	SiO_2	Ca	Mg	Na	K
Krishna	178	38	49	24	29	8	30	2
Cauvery	53	18	39	8	15	16	30	3
Godavari	105	17	9	10	22	5	12	3
Ganga	100	6	9	3	41	6	9	4
Brahmaputra*	56	11	4	7	14	5	7	3
Indus	64	9	15	5	27	1	1	2
Narmada	225	20	5	9	14	20	27	2
Tapti	150	65	1	16	19	22	48	3

*** Present study ; Rest from Subramanian 1987.***

Suspended sediments range from fine sand to clay, the size fraction greater than 12 μm constituting the important size population. They are moderately to poorly sorted with greater amount of finer material in the distribution, reflecting the dynamic nature of the river, particularly during the rainy season. The detrital contribution in the form of Quartz, Feldspar and

Mica make up more than 80% of the mineralogy. Chlorite, Illite and Kaolinite constitute about 95% of the clay minerals.

Table 6B : Brahmaputra river sediment chemistry
(Si to Mg in %. , others in μg/gm)-comparision with other Indian rivers.

Elements	Gan. (N=35)	Bra. (N=26)	Goda. (N=23)	Kri. (N=19)	Cau. (N=21)	Maha. (N=19)	Nar. (N=3)	Tap. (N=3)	Indian average	Bay of Bengal
Si	31	32	27	26	35	12	30	32	25	--
Al	5	6	5	3	5	6	3	4	5	8
Fe	2	5	6	4	2	6	3	1	3	4
Ca	2	2	4	5	2	1	2	8	2	2
Mg	1	2	1	1	1	1	1	1	1	1
Cu	21	61	73	49	12	57	56	126	28	26
Mn	400	457	1060	1040	319	2020	5140	1300	605	529
Zn	46	96	53	31	26	125	50	118	16	--
Pb	23	48	13	9	10	60	5	5	--	--
Cr	52	55	126	68	129	15	--	--	87	84

-- *data not available; Gan-Ganges; Brah-Brahmaputra; Goda-Godavari; Kri-Krishna; Cau-Cauvery; Maha-Mahanadi; Nar-Narmada; Tap.-Tapti; Data-Mahanadi (Chakrapani and Subramanian, 1990),* Krishna (Ramesh and Subramanian, 1988), Godavari (Biksham and Subramanian, 1988); Brahmaputra present work, Remaining from Subramanian et al., 1985.

Sediment chemistry does not reveal significant spatial and temporal variation. However, spatial variation in metal/aluminium ratio in some cases is attributed to continuous addition of freshly eroded materials by a large number of tributaries. Geochemistry of the Ganges and that the Brahmaputra are found to be markedly different with respect to HCO_3, SO_4, Cl, SiO_2, Ca and a few heavy metals like Cu, Fe and Zn.

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