Soil Erosion, Sediment Transport and C-N-P Mobilization: A Case Study of the High Sediment Yielding Brahmaputra River Basin

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Abstract: Understanding of the anthropogenic mobilization rates of Carbon, Nitrogen and Phosphorous (CNP) in the sediments of a gradually urbanizing pristine watershed like the Brahmaputra can provide valuable insight for its sustainable management. The Brahmaputra river basin (catchments area 924,000 km^2), the least studied one in Asia, is currently undergoing rapid industrial, agricultural and economic development in order to fulfill the needs of its exploding population. The paper examines the impact of erosion and sediment yield caused by different anthropogenic activities on the flow and sediment regime of the river as well as on the biogeochemical fluxes of key nutrients like CNP.

CNP concentrations in the matrices of the suspended load and bed load of the main river and the major tributaries flowing through varied land-use terrains over a 700 km. stretch of the Brahmaputra river basin were investigated. The study, based on laboratory analyses of sediment samples collected from thirty eight sampling stations over the basin for particulate nutrient concentrations indicated that soil erosion and sediment discharge in the river basin is highly perturbed by human activities, altering the biogeochemical fluxes of carbon, nitrogen, and phosphorus through the river.

Keywords: sediment, brahmaputra, C-N-P, erosion, biogeochemical flux

1 Introduction

The eastern south Asian region which includes the Brahmaputra basin constitutes one of the first priority regions in global change studies for two major reasons: First, the unique Asian monsoon system passing over the region is of great importance in global hydrological and bio-geo-chemical process of the earth system; Second, the ever-growing human activities, due to rapid economic growth and a large population, constitute the major driving force causing environmental changes such as a rapid increase in soil erosion, deforestation and loss of bio-diversity due to the irrational use of land and biotic resources (Fu and Wang, 1992). Over the past few decades, land-use changes particularly urbanization, agriculture and deforestation in the region have grown to such levels that mobilization rates of carbon, nitrogen and phosphorus (CNP) have become quite high and they are having significant effects on the natural cycles (Galloway and others, 1998).

The Brahmaputra river basin forms a part of the larger natural setting of Southeast Asia and shares many common characteristics. The region embodies an entire range of ecology from the clear mountain headwaters of the Brahmaputra at 5,300 m above sea level flowing through the hilly terrain of Tibet and fertile plains of Assam and Arunachal Pradesh, finally discharging into the Bay of Bengal after passing through the extensive Bangladesh floodplains, covering a distance of more than 2900 km. Therefore the fluvial component of the biogeochemical fluxes in the river and impact due to erosion and sediment load bears much significance. The paper attempts an overview of the recent anthropogenic disturbances to the environmental set-up of the region and the future consequences, particularly on the critical biogeochemical cycles.

2 Methodology

Carbon, Nitrogen, Phosphorous levels in the matrices of the wash-load and bed-load samples collected from the main river and selected East Himalayan tributaries were analysed using standard methods (Mahanta 1999). Data obtained were interpreted with respect to available concentration values for other major rivers so that broad conclusions could be drawn. To understand the changes that are taking place, particularly in the CNP pools of the basin and the way they are being influenced by human activities, data on several anthropogenic factors such as population growth, deforestation, agricultural activities, urbanisation, fertilizer and fossil fuel consumption and construction activities were compiled and interpreted in order to examine how the accelerated erosion and sediment yield caused by changes in land-use and forest cover have affected the biogeochemistry of the Brahmaputra basin.

3 Result and discussion

The climate and environment over the Brahmaputra Basin to a large extent is controlled by the Asian monsoon. The thermal and dynamic influence of the Tibetan Plateau not only plays a critical role in the evolution and formation of the Asian monsoon circulation, but it affects global change as well (An & Thompson, 1998). A considerable part of the Tsan—Po-Dihang basin (as Brahmaputra is known in Tibet and upstream) lies in this area. The Indian and East Asian summer monsoon current penetrate into the south eastern part of this area through the deeply trenched valleys and the upper course of the Brahmaputra, Salween, Mekong and Yangtze and precipitates over this area decreasing rapidly towards the interior of the plateau. Towards south, across the Himalayan mountain belt, the Brahmaputra basin receives heavy rainfall from the passage of South West Indian monsoon from June to September each year. The average normal rainfall in the valley is 2340mm/year with a variation from 1,210 mm/year to 4,590 mm/year (Kalita, 1984). Trend analysis of rainfall for a period of 1901 to 1992 by Srivastava and others (1998) over the Indian sub continent (Table 1) indicates that though the overall rainfall in India does not show any trend, on sub-divisional (meteorological) scale.

Table 1 Districts and Sub Division (Meteorological) showing trend in annual and seasonal rainfall in the states and districts of the Brahmaputra basin (India)

Territory	Annual Rainfall		Seasonal rainfall	
	Increasing	Decreasing	Increasing	Decreasing
Sub Division (Meteorological)	—	Arunachal Pradesh	—	Assam, Meghalaya, Manipur, Nagaland, Mizoram, Tripura
District	Nowgaon	Darrang, Golaghat	Nowgaon	—

(After Srivastava and others, 1998)

Arunachal Pradesh showed a decreasing trend of annual rainfall while all other basin states showed a decreasing trend in the seasonal rainfall. Analysis of annual and seasonal data in a smaller spatial scale, namely at district level, showed that Nowgaon district in the mid-part of the basin showed increasing trend of both annual as well as seasonal rainfall. Since 80% of the flow and 90% of the sediment contribution in the Brahmaputra takes place during the monsoon period (Mahanta, 1999), the seasonal increase in rainfall is of great significance. These variations are of more than simple interest because in the Brahmaputra river basin extreme precipitation events have held an important and often tragic impact triggering devastating landslides and flood.. The 1988 flooding was responsible for 232 deaths and affected 10.5 million people rendering a total damage of 6640 million rupees. The most fertile part of the basin remaining below the flood stage, such variability of climate causes distressing effects on agriculture and the economy. Figure 1 shows the average decadal flood-affected area of the river Brahmaputra and its tributaries since 1956. An increase in the flood-affected area has been observed in the last few decades.

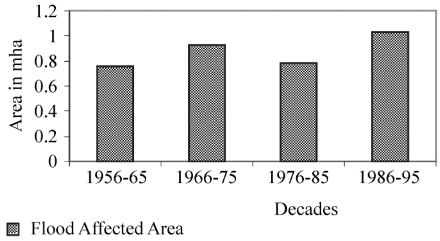

Fig.1 Average decadal flood-affected area of the river Brahmaputra and its tributaries for the period 1956 to 1995

If the increased magnitude and frequency of bank-full discharges in recent years are any indications, it is of great geomorphic significance in the formation of flood (Goswami, 1998). Construction of dams and dykes as long-term flood and erosion protection measures as well as for economic and agricultural development has made its mark in the Brahmaputra basin. The resultant inundation is certain to play a significant role in the light of the enormous water resource potential of the region (Table 2). The aggregate global effect of such large impoundment is difficult to assess, but recent inventories on a broad scale show a potentially important imprint of humans (Dynesius & Nilsson, 1994).

Table 2 Anticipated area of inundation in NE India by major water resource projects

Name of the project	Area of inundation(Sq. km)	Name of the project	Area of inundation (Sq • km.)
Subansiri	154.00	Siang	179.00
Lohit	39.00	Someswari	9.20
Dibang	30.00	Pagladia	51.50
Noadihing	15.00	Kulsi	68.60
Tipaimukh	82.72	Um N Got	11.59
Bhairabi	106.00	Kameng	27.00
		Total area of inundation = 774 Sq • km.	

4 River Discharge and Sediment Flux

Human activities like deforestation and cultivation within an ecosystem cause widespread disturbances and it has been estimated that only a minority of the world's drainage basins (approximately 20%) have near-pristine water quality (Meybeck, 1982). The impact of the anthropogenic changes accumulates across the drainage basin and cascades downstream through large rivers. The accelerated biogeochemical fluxes reflect the collective impact of anthropogenic activities that transform a watershed.

Human management of landscape within the Brahmaputra basin is presently implicated as a major factor controlling the regional runoff, discharge regime and the erosion plus transport of sediment. The river Brahmaputra is ranked fourth among the largest rivers of the world with an average annual discharge of 19,830 m^3/sec (Goswami, 1998). In terms of sediment transport, it is second only to the Yellow river with a sediment transport per unit drainage area of 1128 metric tons per sq. km. The inter-annual variations of flow and sediment discharge for the last 32 years of the river at Pandu (Guwahati) is presented in Fig. 2. From 1975 onwards till 1990 for a period of around 15 years, the sediment yield from the basin shows a sharp increase from 41.5 MT/year in 1975 to 529.6 MT/year in 1990 with a maximum of 621.2 MT/year in 1984. The acceleration of this erosion and transport of sediment can be closely associated with the land use and land cover change in the basin area. Table 3 summarizes the substantial increase in sediment yield attributable to landscape changes due to human activity in numerous settings around the world. The Brahmaputra river basin for the period between 1975 and 1990 experienced more than ten-fold increase in the sediment load.

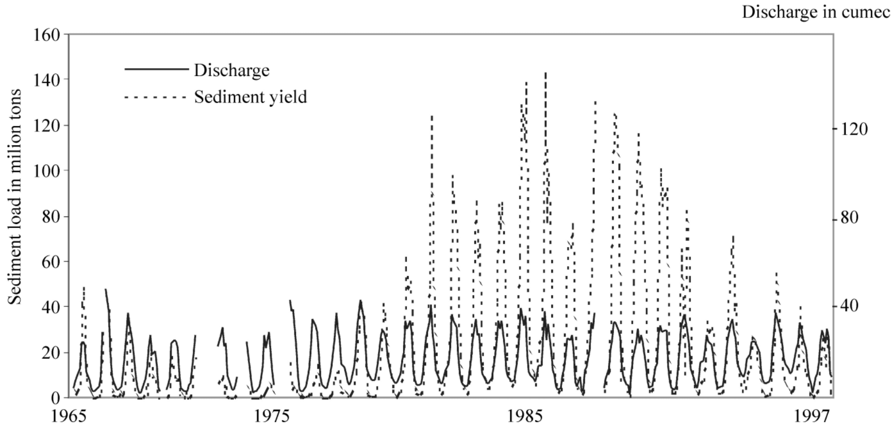

Fig.2 Inter-annual variation of the flow and sediment load of the river Brahmaputra (based on data from the flood control department of Assam)

Table 3 Observed increases in sediment erosion due to various human activities

Setting	Magnitude of increase	Setting	Magnitude of increase
Cultivation in forest land		Erosion of forest roads	
Java	2 times	Idaho	200-500 times
Trinidad	9	Urbanization of rainforest	
Ivory Coast	18	Malayasia	20
Tanzania	5		
Forest clearance		In large rivers, generally	3.5
Cameron Highlands, Malayasia	5		
South Island, New Zealand	Up to 100	In small rivers, generally	8

(After Douglas, 1990)

Accelerated erosion due to deforestation and increased pressure on land due to explosion of population is a major cause of this increase in sediment yield. The total forest cover of the Northeast region is 1,14,992 km^2. While in Bhutan the coverage is 27,650 km^2, in India, Arunachal Pradesh accounted for about 60 percent of the forest cover followed by Nagaland, Meghalaya, Sikkim, West Bengal and Assam. Considerable decline of forest cover was observed in Assam during the period 1976—1977 to 1984—1985. The state lost about 7,922 km^2.(from 28608 to 20686 sq. km.) forest at a rate of about 990 sq. km. per year during that period (Statistical handbook, Govt. of Assam, 1999). However, comparison of the forest cover during the period 1995 and 1997 showed that the rate had declined to 119 sq. km./year and correspondingly the rate of sediment yield also have been observed to have reduced.

The shifting cultivation practiced widely in the catchments increased substantially during the period from 1956 to 1984—1985. The annual area increased by 42 percent (from 0.273 Mha to 0.378 Mha), while the total area affected rose from 1.365 Mha to 1.908 Mha during the same period (Kaul, 1994). The net area under agriculture in the alluvium (74% of the total agricultural area) had increased only by 24 percent during the period 1975—1976 to 1998—1999 against a burgeoning population growth by 57 percent during 1971 to 1991(Fig. 3 & 4). This was because of land constraint and the fact that the area under multiple crops showed a much higher increase rate of 115 percent from 576 Mha to 1,140 Mha during the period 1975—1976 to 1998—1999, reflecting the tremendous pressure on land to sustain a massive population.

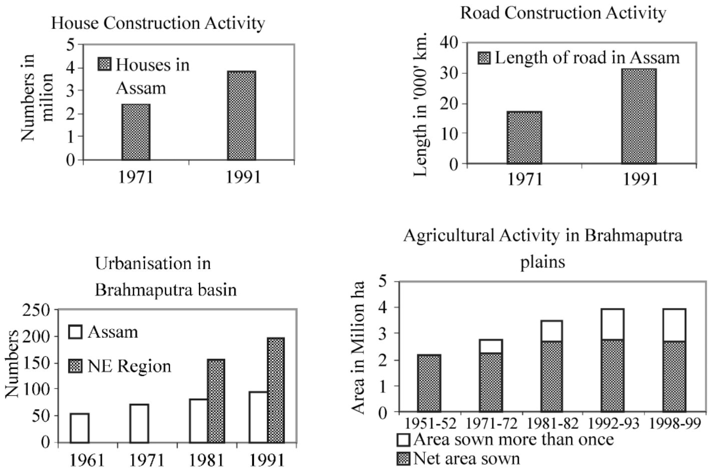

Fig.3 Human perturbations on the change of land cover within the Brahmaputra basin.

5 Biogeochemical fluxes

The Brahmaputra basin has witnessed numerous anthropogenic activities like deforestation, conversion of natural systems to agriculture, wetland destruction, increased application of industrial fertilizer, population growth, and atmospheric deposition etc. These activities have a collective impact on the biogeochemical flux through the fluvial channels of the region. Fig. 4 shows the recent exploitation of key strategic resources and some quantitative aspects of population trend within the basin area.

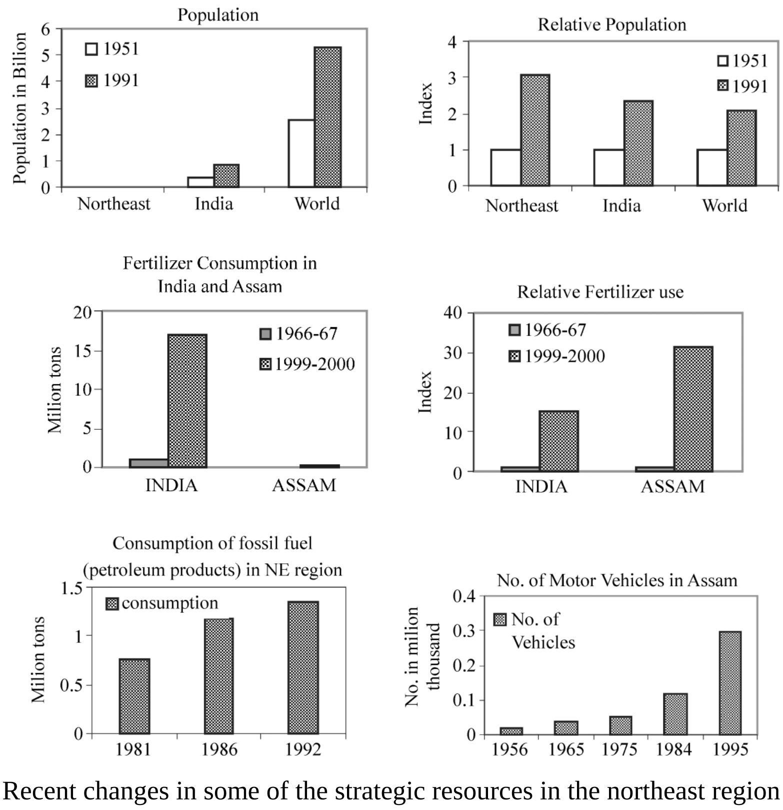

Fig.4 Recent changes in some of the strategic resources in the northeast region of India

The high population density in the Brahmaputra plains (340 persons/km^2.,Census, 2001) rivals the densities of highly developed western Europe. Due to scarcity of data on the region, the all India figures of the anthropogenic emission is shown in Table 4. Energy consumption and so the anthropogenic emission in the basin will continue to rise in the coming years because of the rapid population growth, increased urbanization, greater transport needs, industrial development, and improved standard of living.

Table 4 Summary of anthropogenic emissions from India (1989—1990) in MT

Activities	CO_2	CO	CH_4	N_2O
Energy	614.36	—	0.493	0.052
Industry	23.00	23.00	2.350	—
Agriculture and forestry	553.45	35.22	12.860	0.030
Total	1190.81	35.22	15.600	0.082

After Mehra & Damodaran (1994)

Imprints of these emissions have already started reflecting on the biogeochemical flux from the region. Considering the POC concentration of 0.64% to 1.93% (i.e. 0.5 mg C/l to 17 mg C/l) the flux of particulate organic carbon (POC) through the Brahmaputra river in a downstream location at Pandu was computed as 6.24×10^6 tons/year (Mahanta, 1999) which is estimated to be more than two percent of the global POC load. Particulate nitrogen (PN) in the Brahmaputra varied from 0.21% to 0.38 % (Avg. 0.25%) during pre-monsoon, and 0.08% to 0.11% (avg. 0.1%) during monsoon with an increasing trend along downstream during pre-monsoon (Mahanta, 1999). The flux of PN was estimated to be 8.5×10^5 tons/year. The total phosphorus in suspended sediment particle varied between a minimum of 1,025μg/gm and a maximum of 1,290 μg/gm (monsoon) and 945—1,160 μg/gm (pre-monsoon) with an annual transport of the order of 3.4×10^4 tons P/year which was greater than the particulate phosphorous load for the Amazon (2.8×10^4 tons/ year) (Ruttenberg, 1992).

Table 5 Ambient concentrations and stoichiometric ratios for key nutrients in pristine, rapidly developing and industrialized basins

River	Period	Si(μM)	N (μM)	P (μM)	Si : N	Si : P
Pristine/ near pristine						
Amazon	Before 1972	187	3.2	0.4	58.4	468
	May-June	111—121	7—11	0.3—0.75	12.9	221
Mackenzie	1976	143	7.14	0.19	20.0	752
Yukon	1981—1983	275	8.35	0.35	32.9	786
Zaire	1978—1985	161	7.3	0.72	22.1	224
	Nov.1976	171	5.9	0.89	29.0	192
Industrialized	May 1978					
Mississippi		108	114	7.7	1.0	14
Po	1981—1987	120	147	4.6	0.7	26
Rhine	1981—1984	130	310	14	0.4	9
Seine	1976—1978	120	372	20	0.3	6
Chinese Rivers	1976—1982					
Yangtze		100—105	65	0.5—0.9	1.6	146
Yellow	June 1980	128	64	1.1	2.0	116
Indian Rivers	Aug.1986					
Ganges(middle)#		313	7.17*	13.9	43	23
Brahmaputra**	1984	**160**	**7.17***	**1.26**	**22**	**127**
	1995					

Modified after Vorosmarty and others (1998)

* Calculated from values for basins in pristine/near pristine environment as measured data not available.;

Si, N, P data from Subramanian and others (1987); ** Si, N, P data from Mahanta (1999)

Historical data for the Brahmaputra basin is not available for comparison. However, some of the current figures for C, N and P are comparable to recent concentrations in few major rivers with pronounced human interference. Thus, the present C, N and P concentrations in the Brahmaputra may reflect significant anthropogenic contributions as well. Enhanced fertilizer use could be one major source of P and N (Fig. 4). Table 5 compares concentrations and stoichiometric ratios of inorganic nutrients observed in several large rivers of the world with those observed in case of the Brahmaputra.Relative to the rivers without significant anthropogenic influence (e.g. Amazon, Yukon), concentration of inorganic N and P in highly populated drainage basins (e.g. Po, Rhine) show large increases. The Brahmaputra river although does not indicate such high concentrations currently, its transformation to a non-pristine state is apparent, particularly with respect to phosphorus concentration. In the spectrum from pristine to highly eutrophied drainage systems, the nutrient ratios (indicator of primary production) point towards intermediate position for the Brahmaputra river suggesting growing deterioration of its water quality.

6 Summary and conclusion

Over the past few decades, combustion, agriculture and deforestation in the Brahmaputra basin have grown having significant effects on natural cycles of CNP. In the last few decades, with a high rate of population growth, the region has become a significantly potential CNP source. Although the relative magnitudes of anthropogenic and natural fluxes are still uncertain, it is apparent that carbon, nitrogen, phosphorous cycles are strongly influenced by sediment fluxes from human activities in the region. Much of the unfavorable change of local ecological climate is linked to continuing deforestation and increasing land denudation in the basin as indicated by the present study. However, the seasonal variations, high inter-annual unpredictability and rapid change on larger time scale of the monsoon over the basin would require further research, to establish such a link conclusively. Demographic and socio-economic factors indicated that the current practices of rapid development, land-use and industrialization in the region will increase further and will influence the biogeochemical cycles and emissions of key elements in the region to a great extent, subsequently contributing significantly to the modification of the global cycles of these elements. Keeping in mind that environmental governance usually lags much behind the development rate in under-developed regions like the Brahmaputra basin, apparently this region is quite likely to follow a pathway of development similar to that of the already industrialized and degraded watersheds, thereby jeopardizing the scope of sustainable utilization of its vast water and sediment resources.

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