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Sediment budgets and sinks in the Brahmaputra basin and their agricultural and ecological impacts

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Abstract A multiple regression equation, giving sediment deposition (S_d) in sinks was developed, viz. $S_d = a$[41.73 + 0.181 × *slope* (%) *of the basin* + 0.0046 × *average rainfall* (mm) – 0.387 × clay (%) – 8.125 × *vegetation cover at 1 to 5 scale*]. The values of coefficient *a* for rivers, tributaries, temporary water storages, valleys and lakes and reservoirs were 0.0765, 0.1431, 0.1098, 0.0499, 0.0965 and 0.0100, respectively. The mean annual deposition was 9.5, 48.9, 14.6, 28.3, 23.0 and 31.3 mm, respectively, in the above sinks. The degree of removal of suspended particles by deposition (*S*) in river flow can be determined by the equation, S = antilog(0.69897 + log(Sp/Vav)); where, *Sp* is the average particle size (mm) and *Vav*, is the average flow velocity ($m^3 s^{-1}$) of the river. The soil erosion has caused land degradation and ecological imbalance in the basin.

Key words agricultural and ecological implications; Brahmaputra basin; floods; sediment budgets; sinks

INTRODUCTION

The Brahmaputra basin extends to four northeastern states of India, viz.: Arunachal Pradesh, Assam, Meghalaya and Nagaland. The Brahmaputra River drains an area of 1.94×10^5 km^2 with an average annual flow of 537.2 km^3 of water. The basin is endowed with rich resources of water, soil and vegetation but their indiscriminate use has rendered them in a fragile state (Sharma, 2003). About 455.1 Mt of soil is lost every year through erosion and this huge quantity of soil, along with runoff, takes away large amounts of absorbed and dissolved crop nutrients to different sinks (Sharma & Sharma, 2004). A sediment budget is a quantitative statement of the transfer and storage of sediment as it is transported from its source to its eventual exit from the drainage basin. Due to heavy rainfall in the catchment, the Brahmaputra basin is subject to intense erosion processes. The basin has a steep gradient in the north and in the eastern parts but the slope is extremely gentle in the south, 130 mm km^{-1}. Mismanagement of rainwater causes heavy soil loss in the hills, and silting of river beds and floods in the plains (Sharma, 1998). In the Brahmaputra basin, natural and anthropogenic factors, including the steep gradient, heavy rainfall, prevalence of shifting cultivation, deforestation, free-range grazing, land use and development activities, are the major reasons for soil erosion and sediment yield.

The high sediment load in the runoff can impact on the ecology of the region, but sediment deposition generally improves the fertility and agricultural productivity of crops in the seasonally inundated plains. Erosion and sediment transport are thus part of the natural evolution of the landscape, but constitute some of the most fundamental problems for the development of agriculture, water management and for utilization of natural resources (Kostadinov, 2004). Sediment particle size is the major factor in regulating the behaviour of suspended material in aquatic environments (Nicholas & Walling, 1996) and human accelerated erosion is the major source of sediment in plain areas (Hudson, 1971). This study was undertaken to estimate the total sediment yield displaced from the Brahmaputra basin and the possible amounts of deposition in different sinks en route to its eventual delivery to the sea.

STUDY SITE AND METHODOLOGY

The Brahmaputra basin is in the northeastern region of India (Fig. 1). The Brahmaputra river drains four states viz. Arunachal Pradesh, Assam, Meghalaya and Nagaland. About 15% of the geographical area of Assam and almost the entire area of the other states are hilly. Despite having rich water and land resources, the basin is deficient in food grains.

The methodology for estimating the possible deposition of eroded soil and associated nutrients from the Brahmaputra basin is primarily based on determining the loss of soil and the deposition at different places by quantifying the sediment and nutrient loads in the runoff. Soil loss from erosion was estimated through gauges from different land-use systems prevailing in the region as well as from non-agricultural

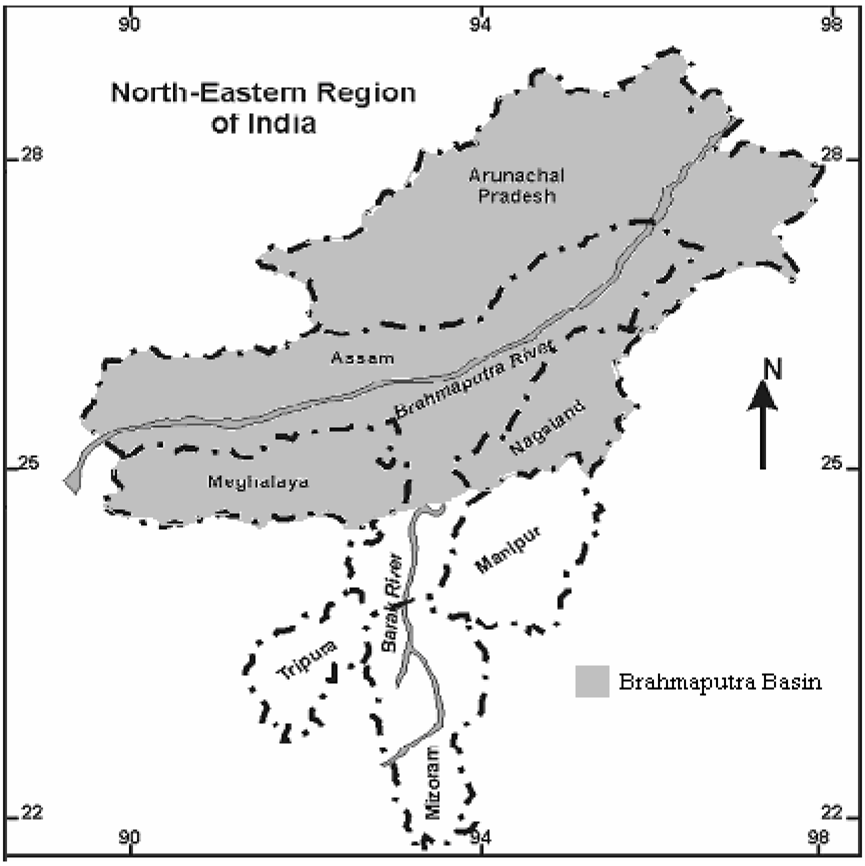

Fig. 1 The Brahmaputra basin in northeastern region of India.

land (Sharma & Sharma, 2004). It may be difficult to determine the exact sediment load displaced from such a large area. However, total soil and nutrient load was estimated as a product of soil loss from the gauged areas of studied watersheds, and extrapolated to the total area of the basin, taking into consideration slope, rainfall, vegetation and clay content of the soil. Deposition of the eroded soil in the sediment sinks was estimated by analysing the water samples for sediment-associated and dissolved elements. The total amount of sediments deposited was determined by multiplying with the quantity of water collected in different sinks. The sediment load transported to the sea was estimated by subtracting the sediment load in different sinks (except the sea) from the total sediment lost from the basin. Nutrient content was estimated by standard procedures (Jackson, 1967).

The coefficient a for different sinks was based on a large body of data on sediment and determined by dividing the sediments deposited in a particular sink by the total sediments transported from the basin. Based on large amounts of available and collected data (Singh & Singh, 1978; Anon., 1982–2003), a multiple regression equation was developed for estimating the total sediment load transported from the basin through runoff. By multiplying the outcome of the regression equation by the value of coefficient a, the amount of sediment (S_d) deposited in a particular sink was determined.

The degree of removal of suspended particles by deposition (S) in the river flow is determined by the equation, S = antilog(0.69897 + log(Sp/Vav); where Sp is the average particle size (mm) and Vav is the average flow velocity ($m^3\ s^{-1}$) of the river. The value of 1 or higher shows that almost all (maximum amount) of sediment is deposited; while values lower than 1 indicate less sediment deposition in the river bed. Values between 0.1 and 1.0 indicate the degree of exchange of sediment with the river bed. The value of 0.1 characterizes the condition where minimum quantities of sediment accumulate on the river bed. Experience shows that, even at higher river flow velocities, there is still some sediment accumulation on the river bed and, therefore S = 0; these situations and those where sediments do not deposit on the river bed at all, have not been considered of much significance.

DISCUSSION

Water resources

The Brahmaputra basin has a riverine length of 14 520 km and the areas under reservoirs, lakes and tanks are 470, 877 and 245 km^2, respectively (Table 1). The basin has surface and groundwater potentials of 1198.4 and 24.0 km^3, respectively. Annually, about 410 km^3 water is received as rainfall. The catchment area of the Brahmaputra basin in India is 0.194×10^6 km^2 and the annual runoff of the river is 537.2 km^3, draining about 76% area of the northeastern region of India.

Factors affecting sediment yield

There are several socio-economic, anthropogenic and biophysical factors which affect the soil erosion and sediment load in the Brahmaputra basin. Shifting cultivation is

Table 1 Water resources of the Brahmaputra basin states.

State	Riverine length (km)	Reservoirs (km^2)	Lakes (km^2)	Tanks/ponds (km^2)
Arunachal Pradesh	2500	3	25	10
Assam	4820	360	838	167
Meghalaya	5600	12	12	18
Nagaland	1600	95	2	50
Total	14520	470	877	245

Table 2 Shifting cultivation, forest depletion and soil and nutrient loss in the Brahmaputra basin states.

State	Shifting cultivation:			Total soil	Annual	Nutrient loss (kt):		
	Annual area (km^2)	Fallow period (years)	Soil loss (Mt)	loss (Mt)	deforestation (km^3)	N	P	K
Arunachal Pradesh	700	3–10	14.5	177.3	50	217	36.6	153
Assam	696	2–10	12.3	178.4	150	201	34.4	155
Meghalaya	530	5–7	14.2	57.7	44	62	7.0	48
Nagaland	190	5–8	8.0	41.7	–	44	5.2	34
Total	2116	2–10	49.0	455.1	244	524	83.2	390

prevalent in 2116 km^2 of the basin, annually, but the total area under its influence is about five times greater. The practice involves cutting of the forest and burning of the vegetation, which has affected the overall ecology of the region. About 49.0 Mt of soil and associated material is lost annually from the shifting cultivation area alone (Table 2). Due to rapid increases in the population growth, the shifting cultivation cycle has shortened from 25–30 years to 2–10 years. Comparative growth trends in the population in the Brahmaputra basin, India, and developed countries generally, show that while population increased by 62% in the developed countries and 190% in India as a whole, the increase was 283% in the Brahmaputra basin, between 1951 and 2001. This has put tremendous pressure on the natural resources, including water, leading to their undue exploitation. Resource degradation, low productivity, the tendency for large family sizes, and little or practically no scope for the application of improved technology, are some of the major drawbacks of shifting cultivation. A total load of 455.1 Mt of soil and 519, 75.5 and 387 kt of nitrogen, phosphorus and potassium, is mobilized every year from the Brahmaputra basin and transported to different sinks on land and the sea (Table 2).

Sediment sinks

Sediment load in the runoff originates from different sources, with the relative contribution varying over time and space due to various erosion processes in the basin. Agricultural activities significantly influence the contemporary geomorphic processes and expansion in the cultivated land and mismanagement of rainwater has increased the rate of soil erosion in the Brahmaputra basin. Information on the suspended sediments provenance is an important requirement in the examination of sediment routing and delivery, and in the construction of sediment budgets (Trimble, 1983;

Walling, 1988). Sediment sources can also exert a fundamental control on the sediment associated transport of nutrients and contaminants in river basins, since the source of the sediment is likely to influence its physical and chemical properties and its contaminant loading. Soil erosion is the main agent of nutrient and contaminant export in the Brahmaputra basin.

From the Brahmaputra basin, storage was estimated through multiple regression, where sediment deposition, $S_d = a[41.73 + 0.181 \times \textit{slope}\ (\%) + 0.0046 \times \textit{average rainfall}\ (\text{mm}) - 0.387 \times \textit{clay}\ (\%) - 8.125 \times \textit{vegetation cover}$ (at 1 to 5 scale)] equating to an annual average of 455.1 Mt (Table 3). This sediment load generally contains sand, silt, clay, gravel, humus and organic carbon. The total organic carbon displaced was 3.05 Mt, which was 0.67% of the total sediment load. Interestingly, the carbon load was 51.4% in the sediments deposited on land as compared to 48.6% in the sediment carried to the sea. The organic carbon content in the sediments deposited in the river, other sinks combined, on land and sea was, 0.61, 0.75, 0.71 and 0.63%, respectively. The low organic carbon content in the sediments deposited in the river bed may be due to the high velocity of water flow. The higher content of carbon in the temporary storages, flood areas, and lake and reservoirs may be due to stagnation of water for a longer period and biological production. The deposition of sediments in major possible sinks in the Brahmaputra basin, calculated by multiplying the total sediments with the coefficient value, was 65.1, 34.9, 49.9, 44.0, 22.7, 4.6 and 233.9 Mt in the river, flooded area, streams/tributaries, temporary water storages, lakes and reservoirs and the sea, respectively (Table 3). The approximate on-land nutrient deposition was 220.0, 33.6, 162.6, 6.9 and 5.2 kt of N, P, K, Mn and Zn, respectively, and the corresponding values of the above nutrients carried to the sea were 299.1, 41.9, 224.2, 10.1 and 5.4 kt respectively. The total load of nutrients carried to the sea was 57.5% as against 42.5% retained in on-land sinks, on a total sediment basis, showing that dissolved nutrients in the runoff retained on-land have less chances of settling down compared to the suspended sediment load.

The mean annual deposition of sediments was 9.5, 48.9, 14.6, 28.3, 23.0 and 31.3 mm in the rivers, flooded areas, streams/tributaries, valleys, temporary water storages, and lakes and reservoirs, respectively. Owens *et al.* (1999) reported that, while the magnitude and duration of sediment storage depends mainly on the sediment supply and hydrological conditions, the stored load may comprise a significant part of a system's annual sediment budget. One of the most important factors defining the

Table 3 Sinks for the soil, nutrients and trace elements in Brahmaputra basin.

Sink	Soil (Mt)	Nutrients (kt): N	P	K	Mn	Zn
River	65.1	58.7	8.8	43.1	1.9	1.4
Flood area	34.9	36.8	5.7	27.6	1.2	0.7
Streams	49.9	54.5	7.8	40.2	1.7	1.4
Valleys	44.0	43.6	6.7	32.5	1.4	1.0
Temporary water storages	22.7	20.7	3.7	15.1	0.6	0.5
Lakes and reservoirs	4.6	5.7	0.9	4.1	0.1	0.2
Sea	233.9	299.1	41.9	224.2	10.1	5.4
Total	455.1	519.1	75.5	386.8	17.0	10.6

sediment supply to river channels is the area of cultivated land within the drainage basin and its dynamics during the period of intensive agriculture. In the Brahmaputra basin, not all the sediments displaced from different locations are transported out of the basin, but about 48.6% of the sediment load is deposited in different sinks in the basin itself.

Implications

Heavy rainfall, deforestation and other human interferences have resulted in widespread soil erosion, loss of soil fertility and decline in agricultural productivity in the Brahmaputra basin. The runoff water goes untapped from the denuded hill slopes instead of infiltrating to recharge aquifers. This has led to a scarcity of soil moisture and even high rainfall areas are without water during winter. In shifting cultivation, the land does not get enough time for rejuvenation and it has affected water resources to a large extent. The region has remained deficient in food grains and the gap is increasing with time (Sharma, 1997). Nevertheless there have been some beneficial outcomes in that the much of the forest litter and humus from the upslope areas gets deposited in the near-valley areas and flood introduced sediments convey relatively high concentrations of nutrients. Thus, whereas monsoon floods can cause widespread damage to growing crops, the inundation can subsequently boost productivity.

An area of ~73 770 km^2 has been degraded in the basin, which is 35.9% of the total basin area. The prevalence of shifting cultivation in the basin has further aggravated the problem of land degradation due to deforestation. Huge amounts of soil eroded from the hill slopes has resulted in silting of river beds, and floods in the plains and valley areas are a common feature. More than 32 430 km^2 of land is prone to floods in the basin, while 3550 km^2 experience floods every year. The scale as well as the frequency of the floods has been increasing year on year (Borthakur, 1992). Deforestation and denudation of the basin have upset the natural water cycle and if unchecked have the potential to lead to disaster. Planning of land and water resources, therefore, assumes great significance and these resources need to be planned, developed and conserved.

CONCLUSIONS

The Brahmaputra basin has plenty of water resources but their misuse has resulted in large-scale erosion of soil and associated elements. Transport of soil and sediment-associated nutrients in the runoff and its deposition in various sinks is a matter of concern. Deforestation and denudation in the basin have led to water scarcity because the natural water cycle has been upset. There is a need to introduce new eco-friendly and sustainable land-use systems to replace shifting cultivation and to discourage deforestation and improve the *in situ* retention of rainwater. Rainwater harvesting and its efficient use can improve the water resource base. Judicious management of rainwater is necessary to reduce runoff. An immediate solution to the water problem requires awareness among users through radical government policies as well as relevant institutional reforms.

REFERENCES

Anon. (1982–2003) *Annual Reports*. Indian Council of Agricultural Research Complex for Northeastern Hill Region, Shillong, Meghalaya, India.

Borthakur, D. N. (1992) *Agriculture in the Northeastern Region*. Bee Cee Publishers, Guwahati, Assam, India.

Hudson, N. W. (1971) *Soil Conservation*. Batsford, London, UK.

Jackson, M. L. (1967) *Soil Chemical Analysis*. Prentice Hall of India, New Delhi, India.

Kostadinov, S. (2004) Soil erosion and sediment transport within small torrential drainage basins of Serbia. In: *Sediment Transfer Through the Fluvial System* (ed. by K. Berkovich, N. Ivanov, S. Kovalev & V. Belyaev), 16–21. Moscow State University, Moscow, Russia.

Nicholas, A. P. & Walling, D. E. (1996) The significance of particle aggregation in the overbank deposition of suspended sediment on river flood plains. *J. Hydrol*. **186**, 275–293.

Owens, P. N., Walling, D. E. & Leeks, G. J. L. (1999) Deposition and storage of fine grained sediment within the main channel system of the River Tweed, Scotland. *Earth Surf. Processes Landf.* **24**, 1061–1076.

Sharma, U. C. (1997) Food security in the northeast. In: *Perspectives for Planning and Development in the Northeastern India* (ed. by R. C. Sundryal, U. Shankar & T. C. Upreti), 197–212. G. B. Pant Institute for Himalayan Environment and Development, Almorah, India.

Sharma, U. C. (1998) Water management by the tribes of northeastern region: the traditional wisdom and future strategies. *Fertilizer News* **43**, 43–49.

Sharma, U. C. (2003) Impact of population growth and climatic change in the quantity and quality of water resources in the northeast of India. In: *Water Resource Systems – Hydrological Risks, Management and Development* (ed. by G. Bloeschl, S. Franks, M. Kumagai, K. Musiake & D. Rosbjerg), 349–397. IAHS Publ. 281. IAHS Press, Wallingford, UK.

Sharma, U. C. & Sharma, V. (2004) Implications of nutrient and soil transfer with runoff in the northeastern region of India. In: *Sediment Transfer Through the Fluvial System* (ed. by V. Golosov, V. Belyaev & D. E. Walling), 488–493. IAHS Publ. 288, IAHS Press, Wallingford, UK.

Singh, A. & Singh, M. D. (1978) Effect of various stages of shifting cultivation on soil erosion on steep hill slopes. *Indian Forester* **106**(2), 115–121.

Trimble, S. W. (1983) A sediment budget for Coon creek basin in the driftless area, Wisconsin, 1853–1977. *Am. J. Sci.* **283**, 454–474.

Walling, D. E. (1988) Measuring sediment yield from river basins. In: *Soil Erosion on Agricultural Land* (ed. by R. Lal), 39–73. Soil and Water Conservative Society, Ankeny, Iowa, USA.