The sediment load of Indian rivers — an update

V. SUBRAMANIAN
School of Environmental Studies, Jawaharlal Nehru University, New Delhi 110 067, India

Abstract This paper summarizes recent information collected on sediment transport in Indian rivers. It reveals the major contribution which Indian rivers make to the total amount of sediment delivered to the ocean at a global scale, but also highlights the large temporal and spatial variability of riverine sediment transport in the Indian sub-continent. This variability is evident not only in the quantity of the sediment transported but also in the size and mineralogical characteristics of the sediment loads.

INTRODUCTION

The present estimate of global sediment discharge at 15-16 $\times$ 10^{16} t year^{-1} (Walling & Webb, 1983) is perhaps an underestimated value due to undetermined values for several minor catchments (Milliman & Meybeck, 1995). Nevertheless, it is now well recognized that the Pacific Oceanic islands and South and Southeast Asia constitute a single geographic region which contributes nearly 80% of the global sediment budget.

Over the years, considerable data have been collected concerning sediment transport in several Indian rivers. For example, Abbas & Subramanian (1984) estimated the sediment load of the Ganges at Farraka Barrage to be 1235 t km^{-2} year^{-1}, which is 8 times the world average erosion rate (150 t km^{-2} year^{-1}) calculated by Milliman & Meade (1983). To improve our understanding of sediment transport processes in South Asia, there is a need to examine recently collected information.

RECENT DATA

A large amount of information has been recently collected for major Indian rivers. For example, it has been shown by Ramanathan *et al.* (1994) that discharge and sediment load for the River Cauvery are linearly related when the information is plotted on logarithmic axes (Fig. 1). Measurements at seven selected locations in the Cauvery system over a period of four water years (1975/76-1978/79) reveal sediment load to change systematically with water discharge (Ramanathan *et al.*, 1994). However, these data also show considerable spatial and temporal variability in the relationship of water and sediment discharge for the River Cauvery (Fig. 2). This variability is believed to reflect the influence of selective mobilization of fine sediment (Ramanathan, 1993) in river transport (Fig. 3). Comparison of rates of erosion and sedimentation in the River Mahanadi (Fig. 4), however, suggests that river transport does not lead to a balance between these processes, and indicates the dominance of deposition of sediment within this system (Chakrapani & Subramanian, 1993).

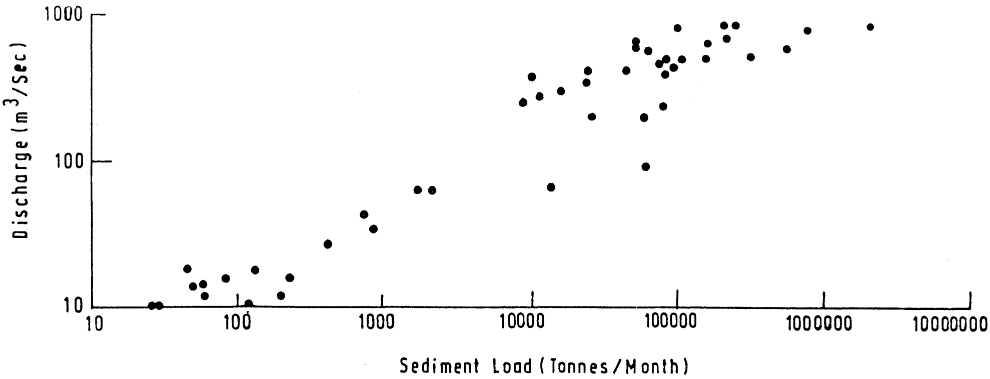

Fig. 1 Relationship between sediment load and discharge at downstream locations in the Cauvery River.

Very large short-term seasonal variation in sediment transport may also occur in Indian rivers. Data collected from the Ganges and Brahmaputra systems (Fig. 5) reveal a more than 5-fold variation in monthly sediment loads over the annual cycle (Singh,

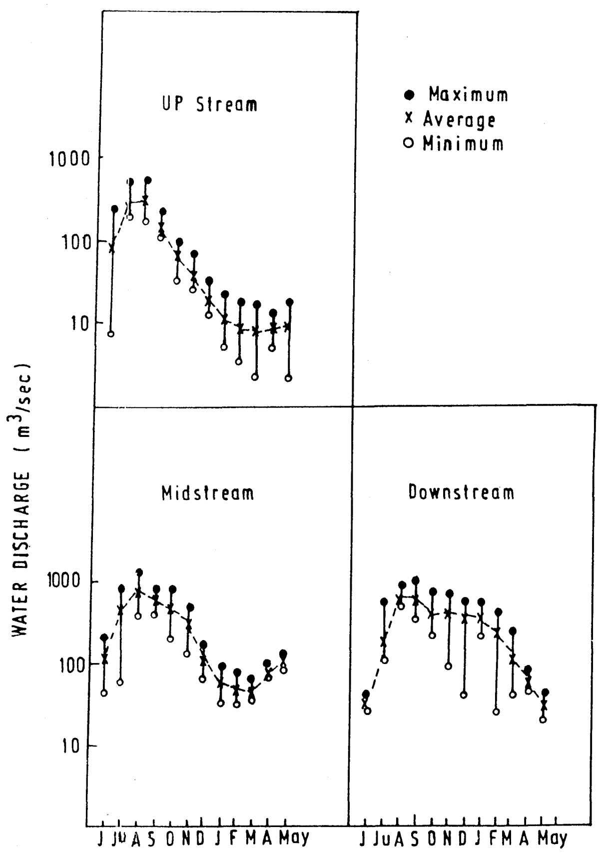

Fig. 2 Spatial and temporal variation of sediments discharge in the Cauvery River.

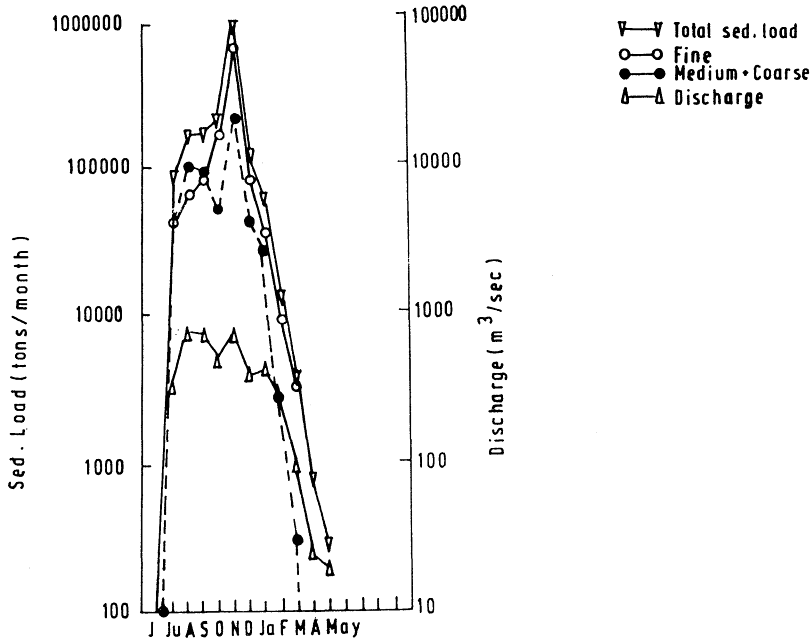

Fig. 3 Monthly variation of discharge and grain-size control on the sediment load of the Cauvery River.

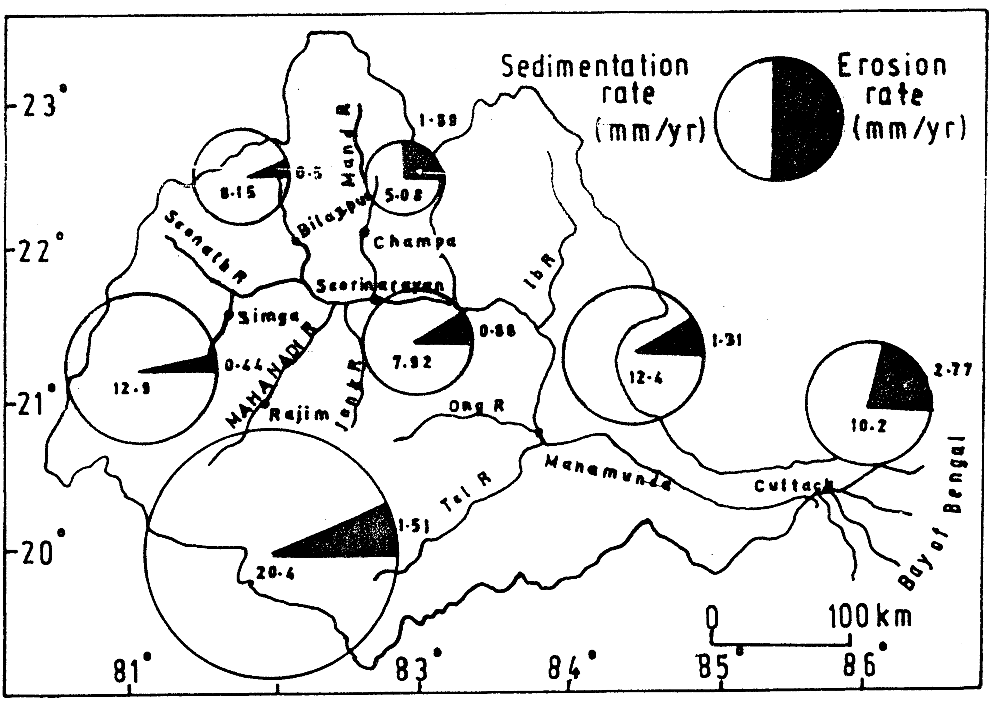

Fig. 4 Comparison of the sedimentation rate and erosion rate in the River Mahanadi.

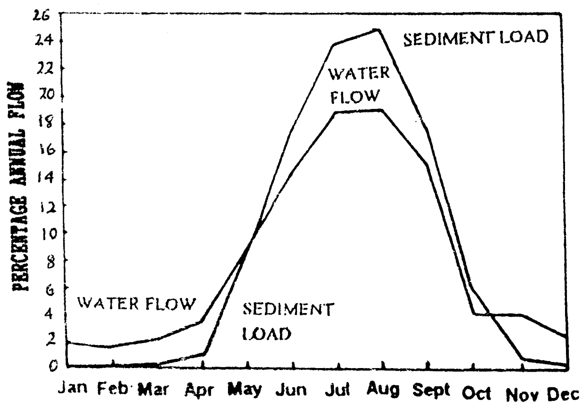

Fig. 5 Average annual water discharge and sediment load carried by Brahmaputra and its major tributaries (compiled from data supplied by the Flood Control Department, Government of Assam).

1988; Chandan Mohanta, 1995). In rivers subject to frequent shifts in course, such as the Kosi River in Bihar (Singh, 1988), there may also be systematic inter-annual variation in the nature of the seasonal cycle of sediment transport, which affects both the magnitude and the timing of peak sediment loads within the year (Fig. 6).

Intra- and inter-annual variability in sediment concentrations and loads is highlighted by data collected for the River Ganges at Patna (Singh, 1988). For example, concentration of the total solid material (TSM) carried by the River Ganges in 1980 varied from a minimum of 11 mg l^{-1} on the 15 March to 2472 mg l^{-1} on 17 August. The ratio of maximum to minimum sediment load varies greatly from year to year, and was recorded at only 25 for 1986 but 225 in 1980. The effect of the monsoon period on the variability of sediment transport in Indian rivers is highlighted by data from the Ganges at Patna, where for 1980 a total of 151 Mt of sediment was carried in the three monsoon months (July-September) compared with only 21 Mt in the remainder of the year (Singh, 1988). Some 88% of the annual sediment load was therefore transported in the monsoon

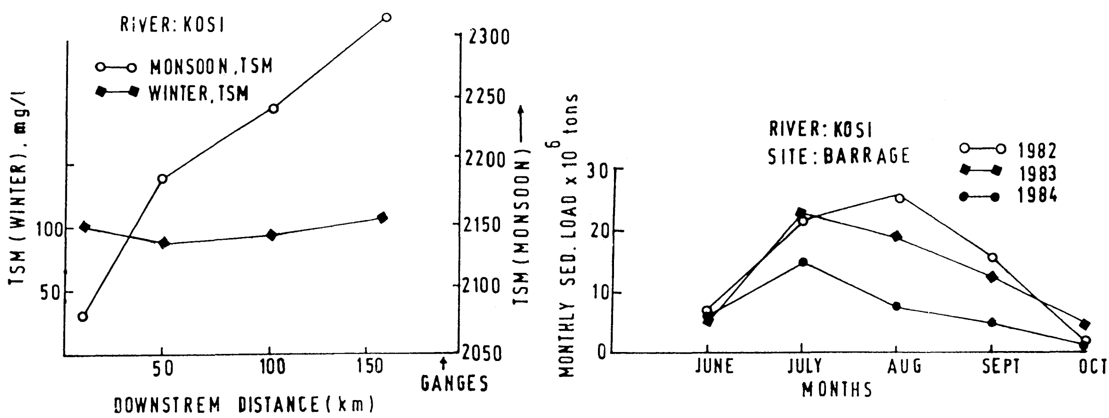

Fig. 6 Monthly variation of sediment load at the Barrage site in the Kosi River in the period 1982-1984 (after CWC).

Table 1 Monthly variation of sediment load in Ganges at Patna.

Months	Discharge (m^3 s^{-1})	Monthly water yield (M m^3)	Monthly sediment yield (Mt)	TSM (mg l^{-1})
January	1 430	3 830	0.33	86.2
February	1 619	3 916	0.36	92
March	1 443	3 865	0.27	70
April	1 020	2 644	0.16	60
May	1 173	3 142	1.92	611
June	2 968	7 693	2.44	317
July	19 775	52 965	40.3	761
August	14 123	37 826	61.6	1628
September	14 265	36 975	48.7	1317
October	5 905	15 808	13.24	837
November	1 002	2 597	1.7	655
December	2 283	6 115	1.4	229
Total		177 377	172	

TSM = concentration of total solid material

period, compared with 76% of the annual water discharge during the monsoon months. In 1980, the peak in water flow, which occurred in July, preceded the peak in sediment transport, which was recorded in August (Table 1). The impact of the monsoon in leading to highly episodic sediment transport has been observed in several Indian rivers. In some years, transport on a single day of the monsoon recorded for rivers such as the Godavari, Mahanadi and tributaries of the Ganges, may account for as much as 50% of the total annual load.

The different size fractions which make up the sediment load carried by the River Ganges have been analysed at several locations within this major river system (Fig. 7). It has to be recognised that changes in sediment load through time, or over space, may simply be reflecting the addition from different sources or the subtraction in different locations of material of a specific size. Other sediment properties, in addition to particle size, are also known to vary in Indian rivers. Clay mineralogy, for example, is known in some Indian rivers to be dominated by illite in May, but by kaolinite in August, and the mineralogy of sediments trapped in sinks, such as the Bengal Delta, Bangladesh can be used to indicate the upstream source areas of the deposited sediments.

The latest available data on the sediment loads of Indian rivers based on information in Ramanathan (1993) and Chakrapani & Subramanian (1993) is summarized in Table 2. The major rivers deliver more than a billion tonnes of sediment annually to the Indian Ocean, although there are large contrasts in the specific sediment yield (t km^{-2} $year^{-1}$) and in the ratio between sediment yield in particulate and dissolved form between the

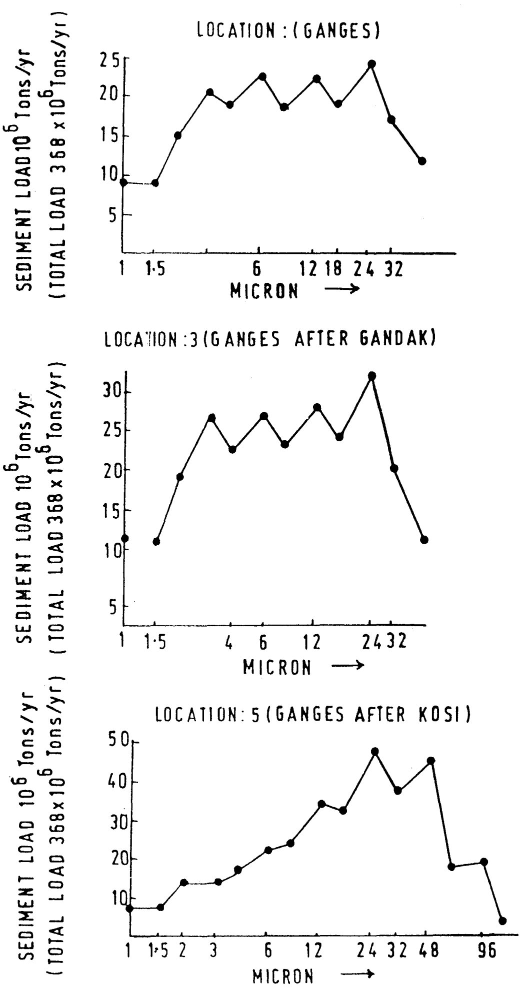

Fig. 7 Sediment load against suspended grain size, Ganges River.

Table 2 Sediment load in major Indian rivers.

River	Discharge ($m^3 \times 10^8$ $year^{-1}$)	Drainage area ($km^2 \times 10^3$)	Load ($Mt\ year^{-1}$): Chemical	Sediment	Total	Erosion rate ($t\ km^{-2}\ year^{-1}$): Chemical	Sediment	Total	Sediment/ chemical ratio
Mahanadi	67	142	9.6	1.9	11.5	67.6	13.3	80.9	0.19
Krishna	30	251	10.4	4	14.4	41	16	57	0.39
Godavari	92	310	17.0	170	187.0	55	555	610	10.0
Cauvery	21	88	3.5	0.04	3.54	40	0.5	40.5	0.01
Ganges	493	750	84.0	329	413	111	438.0	549	3.90
Brahmaputra	510	580	51	597	648	88	865.0	953	9.80

major river systems (Table 2), which reflect differences in their character. The Himalayan rivers are characterised by high water flow, high relief, large catchment areas, and greater instability, involving landslides and earthquakes. Their geology is dominated by unconsolidated rocks of younger formations. In contrast the peninsular rivers are typified by relatively low water flow, low relief, smaller drainage areas and an older and more stable geology. There are also differences between the Himalayan and peninsular rivers in terms of climatic conditions, the degree of urbanisation and in the use of water resources which affect the magnitude and nature of sediment transport.

The construction of dams and reservoirs has meant that not all of the sediment delivered from the tributaries into the mainstreams of the major systems is transported to the ocean. For example, construction of a dam in Marvakonda has greatly decreased sediment transport in the Krishna River with an annual load of 68 million tonnes being recorded above the impoundment and only 4 million tonnes below it. For many Indian rivers, the pattern of erosion and sediment transport has been significantly affected by human activities.

REFERENCES

Abbas, N. & Subramanian, V. (1984) Erosion and sediment transport in the Ganges River basin, India. *J. Hydrol.* **69**, 173-182.

Chakrapani G. J. & Subramanian V. (1993) Rates of erosion and sedimentation in the Mahanadi River basin, India. *J. Hydrol.* **149**, 39-48.

Chandan Mohanta (1995) Distribution of nutrients and toxic metals in the Brahmaputra River basin. PhD Dissertation, Jawaharlal Nehru University, New Delhi.

Milliman, J. D. & Meade, R. H. (1983) Worldwide delivery of river sediments to the oceans. *J. Geol.* **91**(1), 1-21.

Milliman, J. D. & Meybeck, M. (1995) Sediment discharge of world rivers. LOICZ Report (unpublished) April 1995.

Ramanathan, Al. (1993) Chemical studies in the Cauvery River basin. PhD Thesis, Panjab University, Chandigarh.

Ramanathan, Al., Vaidhyanathan, P., Subramanian, V. & Das, B. K. (1994) Nature and transport of solute load in the Cauvery River basin, India. *Wat. Res.* **28**(7), 1585-1593.

Singh, S. K. (1988) Nature of chemical and sediment load in the Ganges River between Sone and Kosi. PhD Dissertation, Jawaharlal Nehru University, New Delhi.

Walling, D. E. & Webb, B. W. (1983) Patterns of sediment yield. In: *Background to Palaeohydrology* (ed. by K. J. Gregory), 69-100. Pergamon, New York.