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Erosion and sediment yield in the Krishna River basin, India

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ABSTRACT The annual sediment load of the Krishna River has been shown to vary regularly with annual runoff over a 6 year period. Similar relationships have also been observed for individual regions of the basin. The quantity of sediment discharged into the Bay of Bengal does not truly reflect the actual sediment load because of the influence of upstream dams. Rates of erosion calculated for various sub-basins indicate that smaller basins erode more rapidly than larger basins. Again, annual variations exist but the erosion rate/basin area relationship is similar every year. While at the river mouth the sediments are texturally uniform, in the upstream region the relative proportions of clay silt and sand vary erratically. The apparent homogeneity at the river mouth is perhaps due to selective sedimentation at the dam sites.

INTRODUCTION

Many of the published sediment data for world rivers (e.g. Gibbs, 1980; Holeman, 1968; Meybeck, 1976) are based on very limited observations on individual river basins. It is now well established that improved understanding of continental fluvial processes and their impact on the oceans requires detailed studies of medium size rivers in Asia. Bikshamiah & Subramanian (1980), Raymahasay (1970) and Subramanian (1979) have briefly reported on the erosional behaviour of a number of Indian rivers. Sediment data for these rivers are generally difficult to collect from various Government agencies, but several Indian rivers have been routinely monitored over the last two decades. Available sediment data for any river basin can be interpreted in terms of basin erosion processes and limited attempts have been made previously (e.g. Subramanian & Dalavi, 1978).

In this paper, discharge and sediment data obtained from the Central Water Commission for the Krishna River basin in India are analysed and certain basin erosion processes are highlighted. While the data available are for the period 1971-1976, the author has been monitoring the sediment load of various Indian river basins since 1976 and it is hoped that the combined data may give a better understanding of erosion of the Indian subcontinent.

THE KRISHNA RIVER BASIN

The Krishna River rises in the Western Ghat mountain range at an elevation of 1400 m and flows for a distance 1400 km before draining into the Bay of Bengal. About 40% of the basin is occupied by mountainous terrain. The Tungabatra and the Bhima are the major tributaries. Except in the upper reaches, semiarid conditions prevail in the basin. The Krishna basin is one of the most intensively utilized basins in India. Archaean and younger crystalline rocks occupy nearly 80% of the basin while the remaining 20% comprises Tertiary Deccan Traps (basaltic) and recent sediments. The Tungabatra tributary flows through 70% Archaean and 30% Precambrian crystalline rock terrain while the Bhima tributary flows through 80% Deccan Trap terrain.

The discharge of the Krishna varies from 3 to 34 000 $m^3 s^{-1}$ (Rao, 1975). Some of the tributaries are totally dry during summer months.

SEDIMENT DATA

Based on monthly observations at 35 measuring stations over a 6 year period (1971-1976), average annual runoff and sediment load for selected locations on the river have been computed and the values are listed in Table 1 along with some hydrological data. Annual sediment load and runoff for the entire basin are plotted in Fig.1. Fig.2 shows the downstream variation in suspended sediment concentration expressed in ppm (parts per million) for the entire

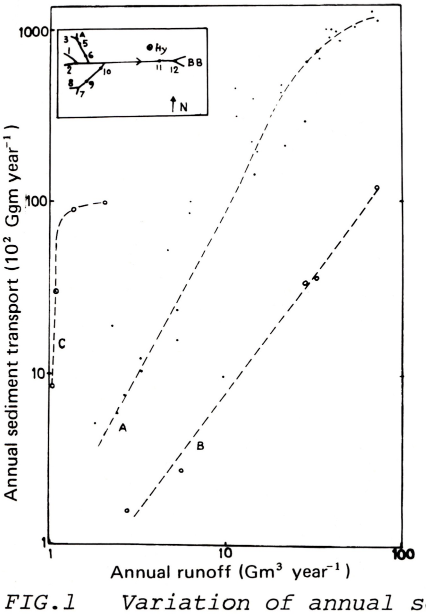

FIG.1 Variation of annual sediment load with runoff in the Krishna basin. A, entire basin; B, at Vijayawada; C, for the Sina tributary. Inset (not to scale) provides a flow diagram of the Krishna system. Numbers correspond to locations in Table 1, columns 1 and 2.

TABLE 1 Hydrological and sediment data for the Krishna River basin for 1975-1976

Location no.	River	Site	Drainage area (km^2)	Runoff ($10^6 m^3 year^{-1}$)	Total sediment transport ($10^4 t year^{-1}$)		Annual mean sediment concentration[a] (ppm)
					Annual	Monsoon only	
1	Krishna	Karod	5 462	5 312	158	139*	298
2	Koyna	Koyna	1 890	2 785	76	75*	274
3	Nira (Bhima)	Sarati	7 200	1 851	103	102	557
4	Sina (Bhima)	Wadakal	12 092	2 159	913	895*	4 230
5	Bhima	Takali	33 196	11 153	1 410	1 362*	126
6	Bhima	Yadgir	69 863	20 522	4 601	3 374*	2 242
7	Tunga (T.B)	Shimoga	3 283	6 701	54	51*	81
8	Batra (T.B)	Marol	4 901	2 544	66	60*	260
9	Tungabatra	Harahalli	14 582	10 519	213	152	203
10	Tungabatra	Bhavapuram	67 180	14 902	1 491	1 490**	1 001
11	Krishna	Srisailam[b]	206 041	70 004	11 689	11 680***	1 669
12	Krishna	Vijayawada[b]	251 360	70 192	1 175	1 063	167

[a] Total suspended matter.
[b] Between Srisailam and Vijayawada there are two major dams.
* = June-October; ** = July-November; *** = June-December; others = June-November

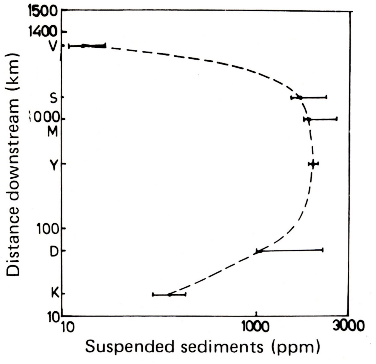

FIG.2 Downstream variation of suspended sediment concentrations in the Krishna River. Tributaries are not shown. Bars represent the range of annual mean values over a 6 year period and dots the 6 year mean values. K = Karad; D = Dannur; Y = Yaperli; M = Morvikoda; S = Srisailam; V = Vijayawada.

stretch of the river. Both the range of values and the annual mean are shown. Computed erosion rates based on the sediment loads from various sections of the river basin are plotted against drainage area in Fig.3.

DISCUSSION

Though the River Krishna originates from a spring in the Western Ghat mountain range, the main source of water is monsoon rain. Throughout the river basin, maximum flow is reported to occur between July and August while the maximum sediment yield takes place between July and October. While Fig.1 shows values of *annual* sediment yield, it must be recognized that more than 95% of the annual sediment load is derived during the monsoon period, as in the Godavari River (Bikshamiah & Subramanian, 1980). Vijayawada is located at the river mouth and there are two major dams on the Krishna about 70 km upstream near Srisailam (Fig.1, location 11 on inset). Upstream of the dams, the river carries an enormous sediment load, which varies

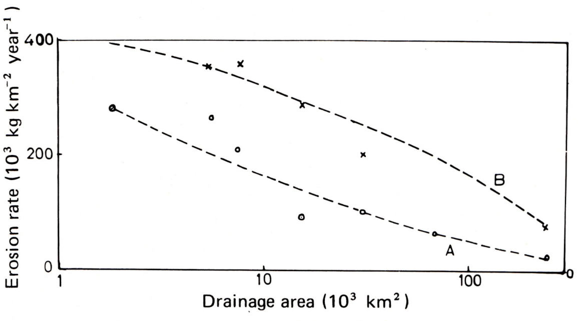

FIG.3 Sediment yields from various sub-basins of the Krishna River system. A, average for 6 year period; B, values for 1975-1976.

annually depending on flood or drought conditions, but below the dams, the sediment concentrations are one tenth of those observed upstream (1669 ppm at Srisailam cf. 167 ppm at Vijayawada). Hence annual sediment transport at the river mouth is small, though showing a systematic relationship with runoff over the 6 year period (Fig.1B). It is also evidence that the increase in runoff is not associated with a proportionate increase in the sediment load. Individual monthly data, not given in this paper, indicate that while runoff may vary by only a factor of four to five, the corresponding sediment load may vary by a factor of five to 30. One of the tributaries of the Bhima, the River Sina (location 4 Table 1, Fig.1) is the main sediment contributor to the River Krishna. The Sina predominantly drains an area of partially weathered Deccan Trap, a geological setting from which sediment particles can be easily released by physical weathering. Fig.1C which relates to the Sina tributary of the River Bhima, clearly demonstrates the influence of this small river on the overall relationship between runoff and sediment load in the Krishna basin.

In calculating erosion rates, several authors (e.g. Gibbs, 1967; Holeman, 1968; Meybeck, 1976; Raymahasay, 1970; Subramanian, 1979) have used sediment data from river mouth location. Fig.1 indicates that due to the presence of dams, the actual sediment yield of the basin does not reach the river mouth and hence continent-ocean sediment balance studies should not be based on such river mouth data.

Fig.2 demonstrates that values of suspended sediment load for the river decrease sharply downstream of the dam region (beyond Srisailam). While the 6 year average value indicated by a dashed line suggests deposition along the river between Srisailam and Vijayawada, the annual and monthly range of values, indicated by bar lines, shows similar trend. A downstream decrease in sediment concentration has been reported for a number of world rivers (e.g. Bikshamiah & Subramanian, 1980; Gibbs, 1967; Meybeck, 1976; Subramanian & d'Anglejan, 1976; Subramanian, 1979). In addition to the influence of deposition, such decreases may also be attributed to dilution from tributaries, although in the case of the Krishna, the tributaries supply a major part of the suspended load. A similar situation exists in the Ganges river system where the Jamuna tributary contributes sediment at their junction (Subramanian & Dalavi, 1978).

Fig.3 demonstrates that drainage area is an important control on sediment yield. Several of the small upstream sub-basins are being eroded more intensively than the entire basin; and the overall erosion rate for the basin may be controlled by the erosion rates prevailing in these smaller sub-basins. Such observations agree with those of Gibbs (1967) for the Amazon system where a large proportion of the sediment load is derived from a small Andean subsystem. Both long term averages (Fig.3A) and values for individual year (1975-1976, Fig.3B) indicate that erosion rates are highest in small basins. With such high rates of erosion, the small basins will reach base level very much earlier than the entire basin, and erosion rates computed for large basins may be meaningless without corresponding values for sub-regions.

Based on data for the river mouth, Subramanian (1979) estimated that the Krishna basin is being eroded at the rate of 4 000 kg $km^{-2} year^{-1}$ and that in 12 million years, the basin would be reduced to mean sea level (Subramanian, 1978). Similarly, Gibbs (1980) calculated that the time needed to fill the shelf regions of various river mouths varies from 3 000 years for the Ganges to 1.2 million years for the Yensei. In all such calculations, both sediment load and erosion rate in the river basins are assumed to be constant with time. Data plotted in Fig.3 clearly show that there are annual variation in these values and for basins with intensive land use such as the Krishna, such variations could involve a factor between five and 30. Furthermore, due to the high erosion rates in the small sub-basins contributing the bulk of the sediment load, these regions would reach base level within a time scale different from that expected for the entire region. Hence, no further supply of sediments will take place to the main river system.

Throughout the Krishna basin, the particle size distribution of suspended sediment varies erratically, longitudinally, seasonally, as well as annually. Generally, sand and coarser particles are not abundant and may comprise less than 10% of the sediment. In the upstream region (location 1, Table 1), the proportion of silt/clay particles varies from 1:1 to 9:1, whereas at the river mouth (Vijayawada), the ratio is generally constant around 1:1, throughout the year and also every year. The Tungabatra tributary shows extreme variations in the size distribution with the clay/silt ratio varying from 1:20 to 1:2. At Srisailam, upstream of the dams, the clay/silt ratio varies up to 1:5 and the relative uniformity at the river mouth may perhaps be due to selective sedimentation in the dam region.

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