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TEMPORAL, SPATIAL AND SIZE VARIATION IN THE SEDIMENT TRANSPORT IN THE KRISHNA RIVER BASIN, INDIA

R. RAMESH* and V. SUBRAMANIAN

School of Environmental Sciences, Jawaharlal Nehru University, New Delhi-110067 (India)

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ABSTRACT

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The total sediment transport of the Krishna River to the Bay of Bengal is estimated to be 4.11×10^6 ton yr^{-1}. The sediment load decreases sharply from 67.72×10^6 ton yr^{-1} from the upstream region ((Morvakonda) to 4.11×10^6 ton yr^{-1} at the river mouth (Vijayawada). The depletion of sediment supply in the river mouth and lack of uniformity in sediment transport within the basin is mainly due to several human activities such as dams, cropping, etc. This has been substantiated by the temporal and spatial variation of the suspended sediments based on fourteen years data (1971–84). One of the tributaries of the Krishna, the Bhima River is the main sediment contributor to the Krishna with an average annual sediment transport of 25.91×10^6 ton and sediment concentration of 2070 mg l^{-1}. The bulk of sediment transport (> 95%) takes place in the monsoon period. Erosion rate shows no systematic relationship either spatially or temporarily. The total sediment erosion of the Krishna is estimated to be 16 ton km^{-2} yr^{-1}. Rates of erosion calculated for various subbasins indicate that smaller basins erode more rapidly than larger basins. The particle size distribution of the suspended sediments were correlated with the mean monthly sediment transportation to evaluate the downstream and temporal variation of grain size with sediment transport. At the river mouth, it is seen that enormous amounts of fine particles (1–10 μm) add to the monthly sediment load of the river.

INTRODUCTION

In material transport, the river plays a very important role. More than 90% of the continental weathering products are transported by rivers to the oceans (Garrels et al., 1975). Over the past two or three decades growing awareness of the wide ranging environmental significance of the suspended sediment transport by rivers has generated a considerable body of information concerning the magnitude of sediment yields and their control by human activity, climate and other catchment characteristics (e.g. UNESCO, 1982; Peart and Walling, 1986). Many relationships between solid and dissolved

* Present address: Department of Geological Sciences, McGill University, 3450 University Street, Montreal, Que. H3A 2A7 (Canada)

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transport rates and environmental factors have been described by several authors (Leopold et al., 1964; Judson and Ritter, 1964; Gibbs, 1970). It is now well established from earlier workers (e.g. Meybeck, 1976; Milliman and Meade, 1983) that improved understanding of continental fluvial processes and their impact on the oceans requires detailed studies of medium size rivers in Asia. Erosion and sediment transport of a number of Indian rivers are reported briefly by several authors (e.g. Subramanian, 1979; Bikshamiah and Subramanian, 1980; Abbas and Subramanian, 1984) based on very limited observations. There is no systematic long-term monitoring programme and most of these studies were restricted to short-term studies with a restricted monitoring programme over a period of one to two years. The sediment and discharge data vary monthly, seasonally and annually in most of the river basins, and hence these short-term studies can result in large-scale under- or overestimations of load. In this paper, an attempt has been made to give a comprehensive picture of Krishna River sediment transportation and its relation with grain size distribution based on long-term data. In this study, seasonal observations of suspended sediment variations for the period 1981–84 were made. In addition, monthly discharge and sediment data for the period 1971–81 (except 1976–77) were obtained from the Central Water Commission, Government of India. Both the sets of data were processed together to evaluate the sediment yield and erosion characteristics in the Krishna River basin.

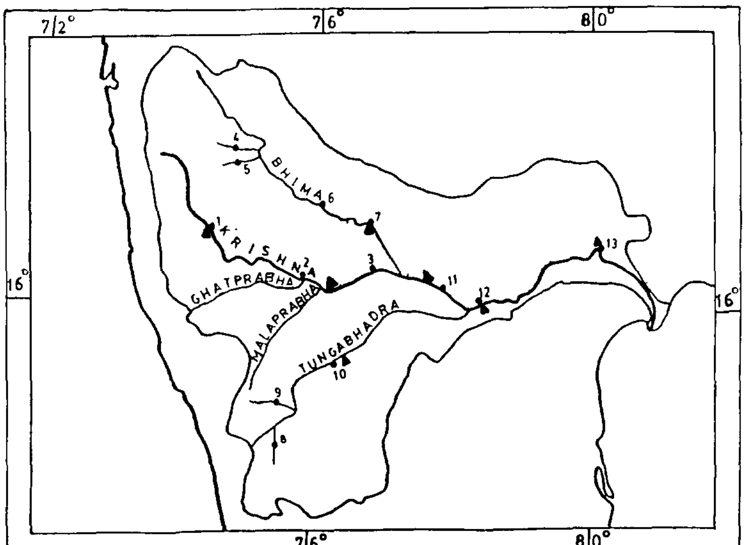

Fig. 1. Map of the Krishna River basin with sampling locations. Numbers 1 to 13 correspond to locations in Table 1, column 2 and 3. For clarity, only some important sampling locations are shown (triangles) for the samples collected between 1981–84.

TABLE 1

Hydrological and average sediment data for the Krishna River basin (from 1971–81)

Location no.	River	Site	Drainage area (km^2)	Annual runoff (10^6 m^3)	Total sediment transport	Annual monsoon* (× 10,000 ton)	Annual mean sediment concentration (mg l^{-1})	Erosion rate (ton km^{-2} yr^{-1})
1	Krishna	Karad	5462	4518	169	168	372	275
2	Krishna	Bagalkot	8610	3388	281	272	803	327
3	Krishna	Huvanur	11400	1751	917	876	4862	804
4	Nira	Sarati	7200	1531	232	231	983	203
5	Sina	Wadakbal	12092	1136	648	636	5949	525
6	Bhima	Takali	33916	7362	953	950	1209	289
7	Bhima	Yadgir	69863	11495	2591	2578	2070	369
8	Tunga	Shimoga	2831	5473	37	37	63	130
9	Varadha	Morol	4901	2062	72	70	332	146
10	Tunga-Bhadra	Harlahalli	14582	8144	145	138	175	99
11	Krishna	Bawapuram	67180	6923	638	630	945	94
12	Krishna	Morvakonda	210500	41873	6772	6765	1572	322
13	Krishna	Vijayawada	251360	32397	411	410	122	16

*June to November.

KRISHNA RIVER BASIN

The Krishna River catchment lies between 13° N and 19° 30′ N; and 73° 23′ E and 80° 30′ E. The basin map of the Krishna is shown in Fig. 1. The river rises in the western Ghats from a slender spring near Mahabaleshwar at an elevation of 1337 m, about 64 km from the Arabian Sea. Some of the hydrological characteristics are given in Table 1. Drainage area and annual runoff data for the different locations were obtained from the Central Water Commission (unpublished report) and from Rao (1975). The Bhima and Tungabhadra are the major tributaries. Except in the upper reaches, semi-arid conditions prevail in the basin.

Archaean and younger crystalline rocks occupy nearly 80% of the basin while the remaining 20% comprises Tertiary Deccan Traps (basaltic) and recent sediments. The Tungabhadra tributary flows through 70% Archaean and 30% Precambrian crystalline rock terrain while the Bhima tributary flows through 80% Deccan Trap terrain.

METHODOLOGY

One-litre water samples were collected in polythene bottles four times (April 1982; February 1984; June 1984; and August 1984) at sixteen stations in the entire region of Krishna River basin and its major tributaries. Fig. 1 shows the sampling locations. In addition, five-litre water samples were collected at a few locations during the month of June and August 1984 to study the grain size distribution. The size distribution of the suspended sediments was determined using a model TA 11 Coulter Counter interfaced with an Hewlett-Packard ’85 desk-top computer.

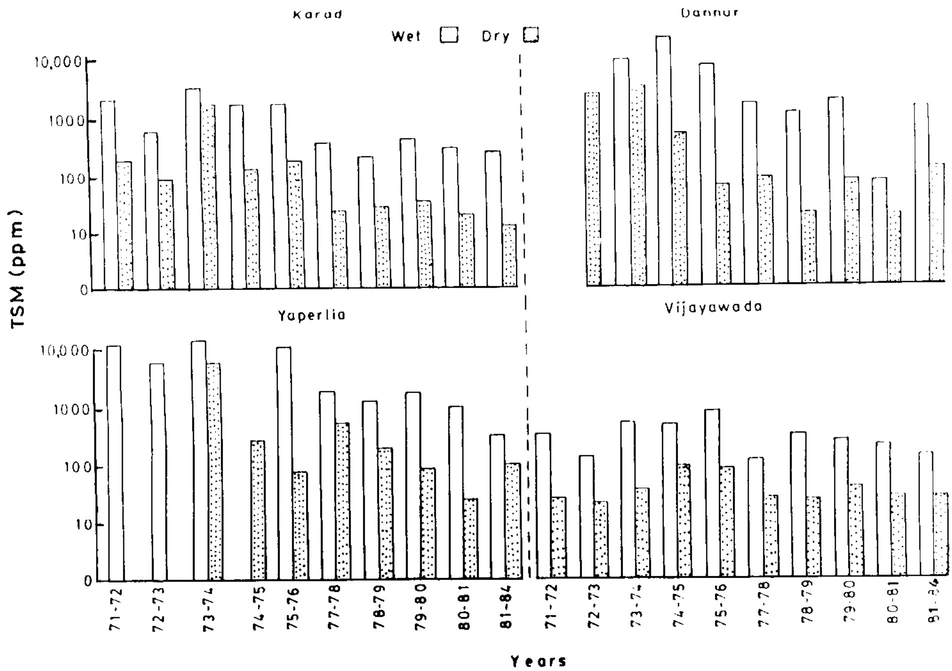

Fig. 2. Seasonal variation of TSM during the year 1971–84.

RESULTS AND DISCUSSION

Temporal and spatial variation of the suspended sediments

Average annual runoff, sediment load, sediment concentration and erosion rate for selected locations (Fig. 1) on the river have been computed based on ten years (1971–81) data and the values are listed in Table 1, along with some hydrological data. Table 1 points out that the tributaries carry relatively less Total Suspended Sediments (TSM) except the Bhima. The Bhima is the main sediment contributor to the Krishna River. The Bhima predominantly drains an area of partially weathered Deccan Trap, a geological setting from which sediment particles can be easily released by physical weathering. Semi-arid climate and high runoff also influence the environment of TSM in the Bhima. The sediment load and TSM varies widely within the basin. For example, a threefold increase in sediment load and a sixfold increase in TSM for the Krishna between Bagalkot and Huvanur has been observed (Table 1). This significant increase in both sediment load and TSM is perhaps due to the influence of tributaries Ghataprabha and Malaprabha which were not sampled for the present study. Relatively high TSM values were observed upstream as compared to downstream in all years. Sediment delivered from the upland areas is trapped within the basin mainly due to several human activities. For

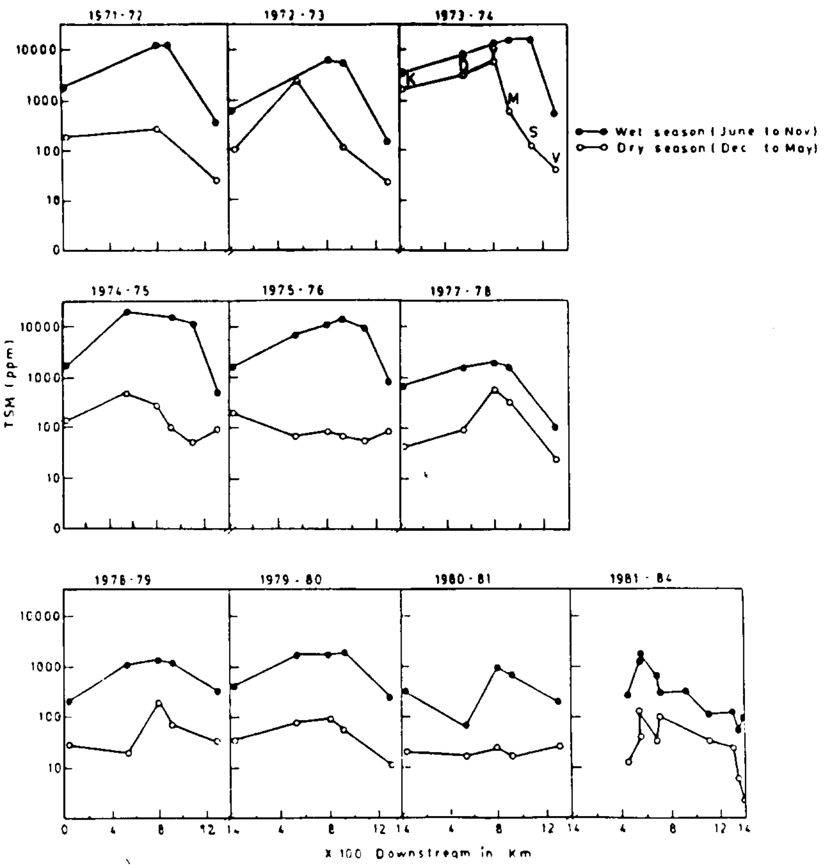

Fig. 3. Downstream variation of TSM with season during the year 1971–84. D = Dannur; Y = Yaperli; M = Morvakonda; S = Srisailam; V = Vijayawada.

example, engineering structures in rivers may disturb the natural sedimentation processes. The maximum to minimum range of TSM in the Krishna for individual years, not shown in this paper, varies by a factor of three upstream and by a factor of seven downstream. The Tungabhadra has not shown much annual variation except in 1971–72, whereas the Bhima varies by a factor of four. From Table 1 we can also infer that more than 95% of the annual sediment load originates during the monsoon period (June–November).

The seasonal variation of suspended sediments during wet season (June–November) and dry season (December–May) for a 14 yr period (1971–84) for four important locations in Krishna from upstream to downstream are shown graphically in Fig. 2. Irrespective of the temporal and spatial variations, the concentration of the suspended sediments seems to be in same proportion of approximately 2:1 with respect to the wet and dry season. Particularly at Vijayawada, the historical sediment concentration appears to remain quite uniform from wet to dry season. This can be also seen in the line of the best fit

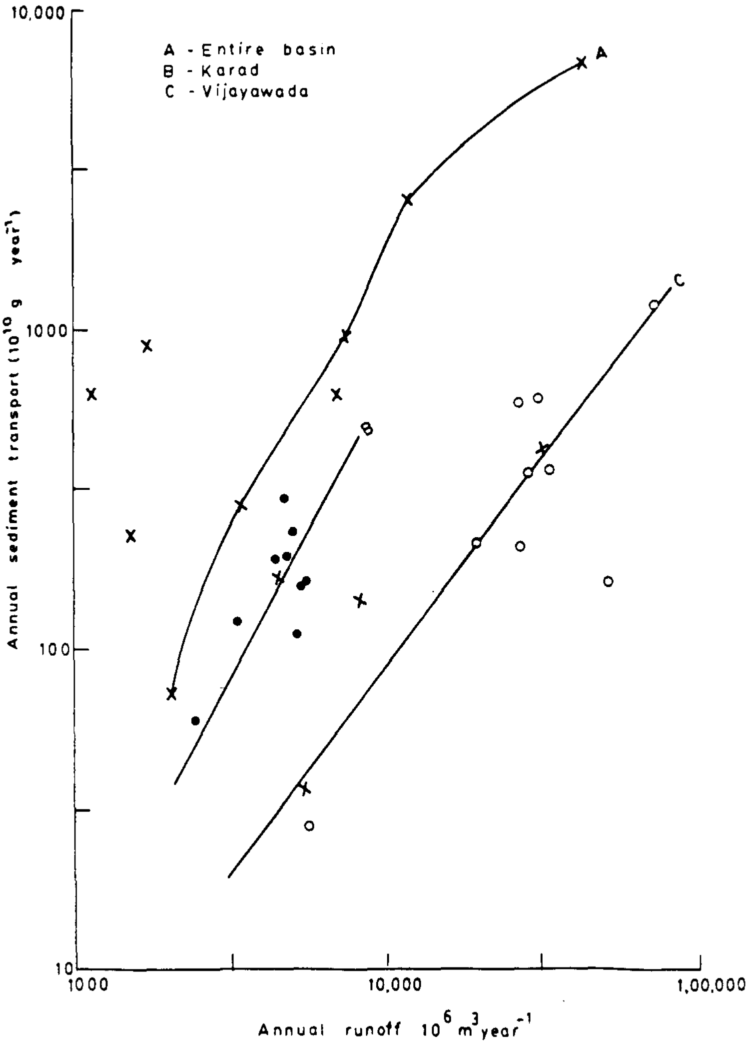

Fig. 4. Variation of annual sediment load with runoff in the Krishna River basin.

of Fig. 4. Subramanian (1978) reported significant seasonal variations in suspended sediment load on major Indian rivers. He also reported that during the monsoon all non-Himalayan rivers except the Cauvery carry a sediment load greater than 1000 ppm. The present study also shows (Fig. 2) that except at Vijayawada all the suspended sediment contents are greater than 1000 ppm. There are two major dams in between Srisailam and Vijayawada. The suspended sediments settle down at the dams, and hence the sediment concentration at Vijayawada is one-tenth of that observed upstream both in wet and dry seasons.

Figure 3 demonstrates the downstream variation of suspended sediments in wet and dry seasons for the 14 yr period. The suspended sediments for all the years decrease sharply downstram of the dam region (beyond Srisailam) in both seasons. A downstream decrease in sediment concentration has been reported for a number of world rivers (e.g. Gibbs, 1967; Meybeck, 1976; Subramanian, 1979; Bikshamiah and Subramanian, 1980).

Sediment transportation

Figure 4 shows a systematic relationship between runoff and sediment transport over the 10 yr period. At Vijayawada station during low flows a twofold increase in flow occurs from about 5000–10,000 × 10^6 m^3 yr^{-1}; about a 100-fold increase occurs in the sediment transport. Conversely, at high flow in the 10,000–100,000 × $10^6 m^3 yr^{-1}$ range only a two- to threefold increase in sediment transport occurs. Figure 4 also shows evidence that the increase in runoff is not associated with proportionate increase in the sediment load. For example, the annual sediment transport at the river mouth is small when

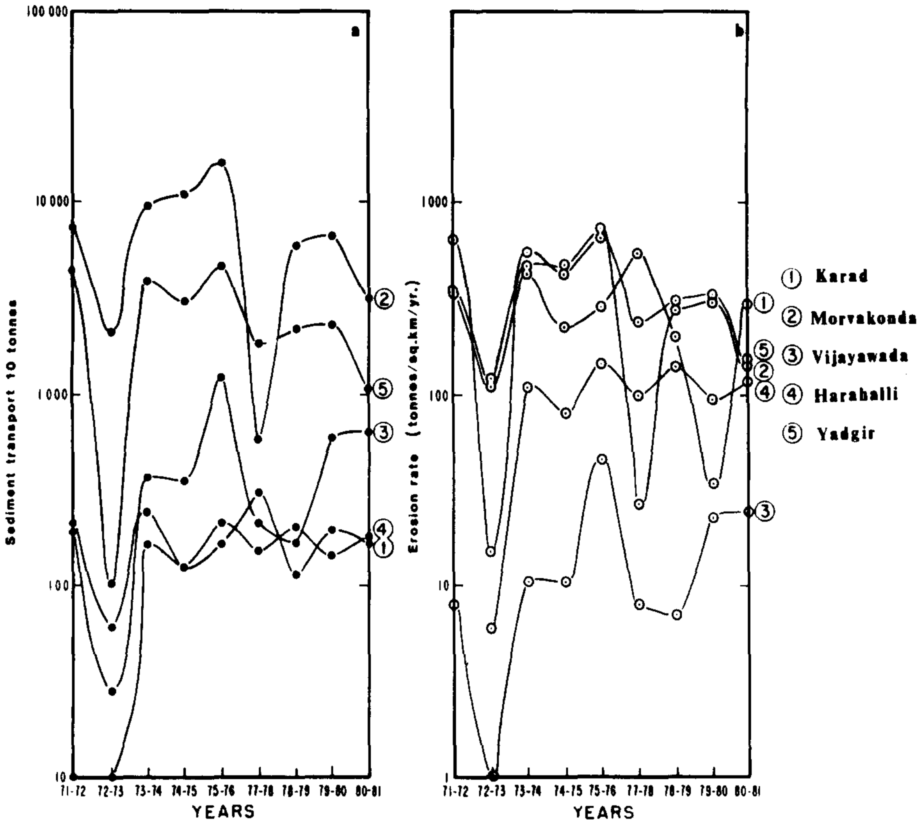

Fig. 5. (a) Annual variation of sediment load; (b) annual variation of erosion rate.

compared to annual runoff (Fig. 4c) which may be due to the influence of dams. Upstream of the dams, the river carries an enormous sediment load, but below the dams, the sediment concentration show only about 13% of those observed upstream (1572 mg l^{-1} at Marvokonda and 122 mg l^{-1} at Vijayawada).

Figure 5a shows the annual variation of sediment transport for the Krishna River and its major tributaries. The individual year data ranges from a minimum of 0.28 $\times$ 10^6 ton for the year 1972–73 to a maximum of 11.75 $\times$ 10^6 ton for the year 1975–76. The mean annual sediment transport of the Krishna River is estimated to be 4.11 $\times$ 10^6 ton (Table 1). These sediment transport and erosion rates are based on continuous study for the 10 yr period. Thus, these rates would not change significantly unless major changes, such as floods, droughts, or any other significant changes in flow take place. To avoid the discharge fluctuations from one year to another, the 10 yr average discharge was used in sediment transport calculations. Upstream of dams, the river carries an enormous sediment load of 68 $\times$ 10^6 ton. Below the dams, i.e., at Vijayawada, there is a sudden depletion of 64 $\times$ 10^6 ton of sediment load to 4 $\times$ 10^6 ton. Most of the sediments settle in this area and the sediment load of the basin does not reach the river mouth. The Krishna River contributes relatively less sediment than other Indian and world rivers (Ramesh and Subramanian, 1986). For example, according to recent estimates the Godavari River basin (Biksham 1985), which has more or less the same drainage area and

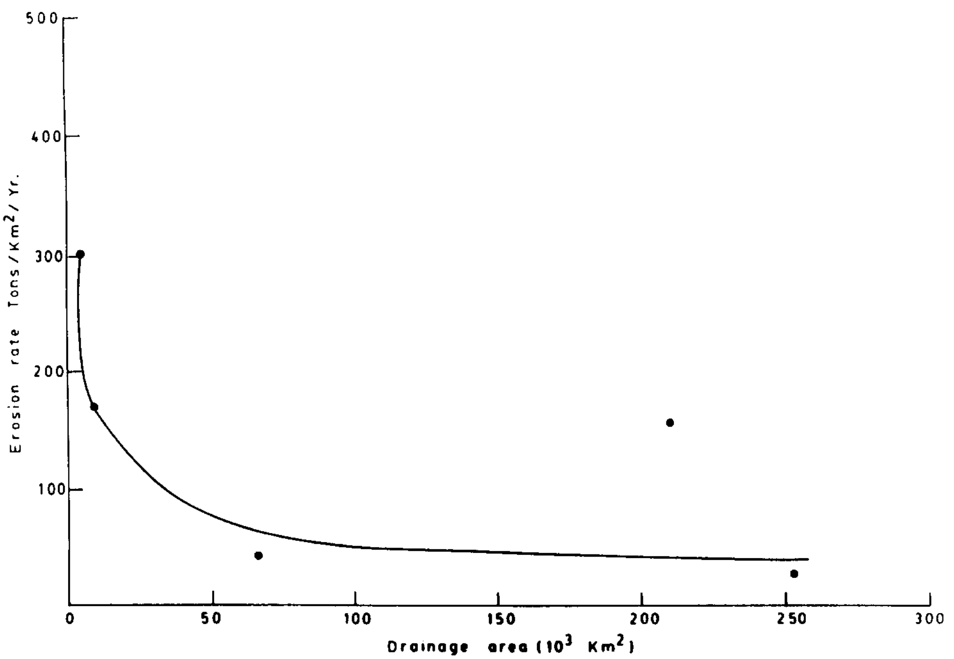

Fig. 6. Variation of erosion rate with drainage area in various subbasins of the Krishna river system.

water discharge as the Krishna, contributes 170 × 10^6 ton of sediments annually.

Erosion rates

The rate of erosion, which is the index of intensity of erosion in a river basin, is expressed in ton km^{-2} yr^{-1}. Recent estimates (Ramesh, 1985) show that the total erosion rate of the Krishna River basin is 57 ton km^{-2} yr^{-1} (41 ton km^{-2} yr^{-1} chemical + 16 ton km^{-2} yr^{-1} sediment). The sediment erosion rate of the Krishna River is much lower as compared to any other Indian (except the Cauvery) and world rivers (Ramesh and Subramanian, 1986): Indian average 46.8; world average 150; and Cauvery 0.5 ton km^{-2} yr^{-1}. Figure 5b shows the fluctuations in annual erosion rates. There is no constancy with time, which is mainly perhaps due to human interference rather than natural erosion process. Based on the data for the river mouth it has been estimated an average erosion rate of 2 mm 100 yr^{-1} and that in 2.17 × 10^6 yr, the basin would be reduced to mean sea level.

Relationship between erosion rate and drainage area

Figure 6 demonstrates that drainage area is an important control on sediment yield. Several of the small upstream subbasins are being eroded more

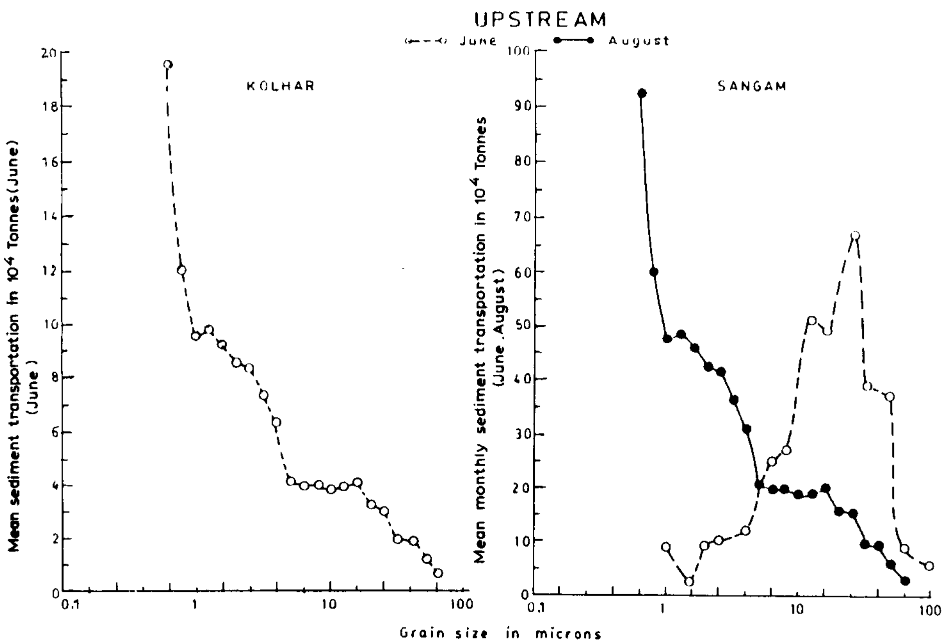

Fig. 7. Grain size vs. mean monthly sediment transportation in upstream reaches of the Krishna River basin. Total sediment transportation at Kolhar in June is 124.63 × 10^4 ton; at Sangam in June 358.47 × 10^4 ton; and in August 354.30 × 10^4 ton.

intensively than the entire basin and the overall erosion rate for the basin may be controlled by the erosion rates prevailing in these smaller subbasins. 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. Figure 6 indicates that erosion rates are higher 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 of subregions.

Relationship between grain size and sediment transportation

Five samples collected in June and four samples collected in August 1984 at the same sampling points of the Central Water Commission were chosen to correlate grain size with the sediment transportation. Mean monthly sediment

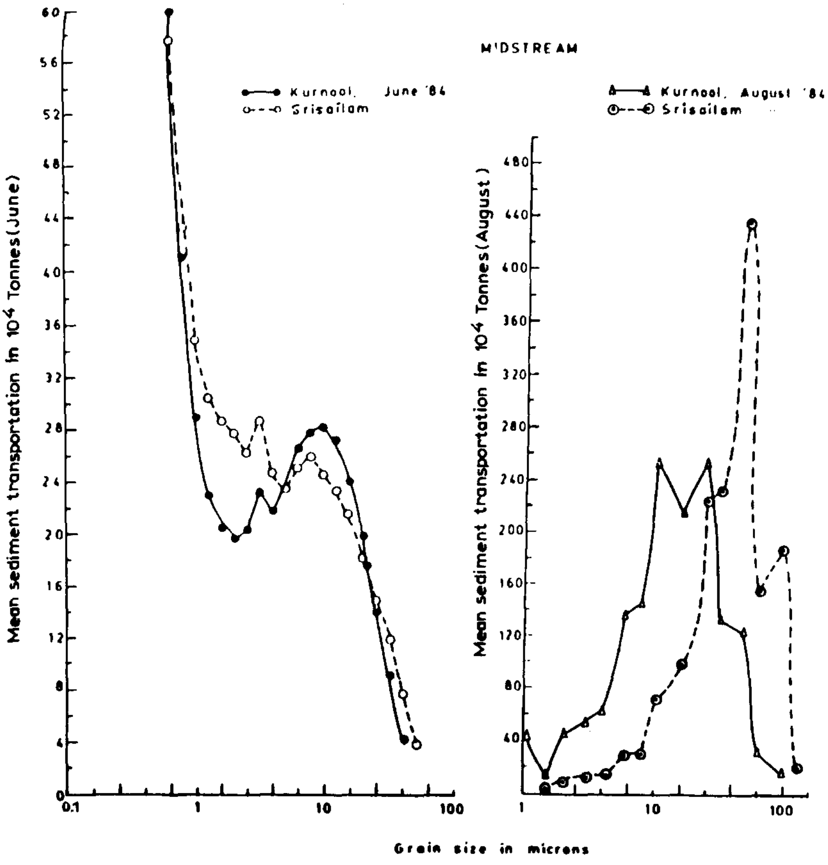

Fig. 8. Grain size vs. mean monthly sediment transportation in midstream reaches of the Krishna River basin. Total sediment transportation at Kurnool (June) is 462.67 × 10^4 ton, (August) 1549.92 × 10^4 ton; and at Srisailam (June) 499.91 × 10^4 ton, (August) 1560.03 × 10^4 ton.

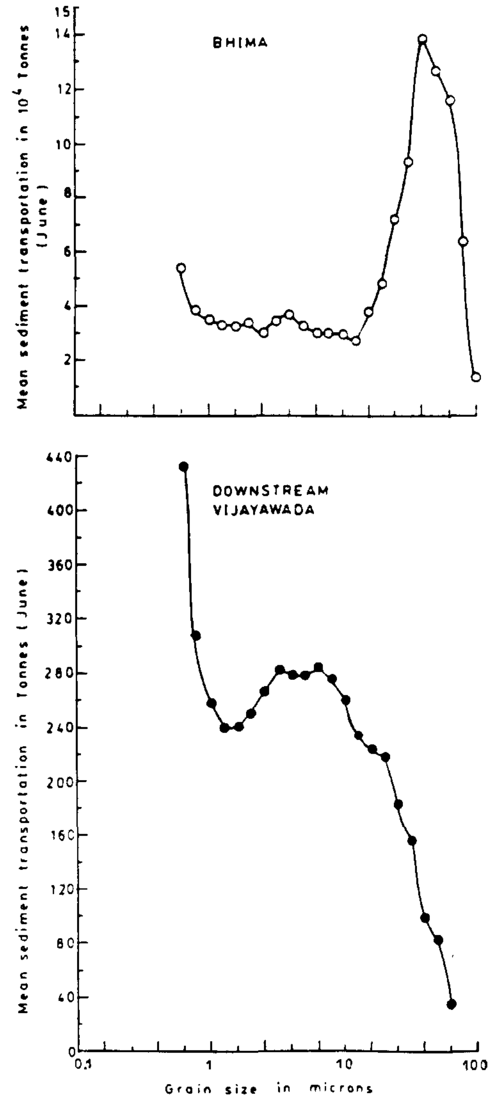

Fig. 9. Grain size vs. mean monthly sediment transportation in downstream reaches and a tributary of Krishna. Total sediment transportation at Vijayawada (June) 0.49 × 10^4 ton and at Bhima (June) 118.73 × 10^4 ton.

transportation was calculated from the 10 yr data for the months of June and August and plotted against the grain size at different size intervals. Figures 7, 8 and 9 clearly demonstrate the temporal and spatial variations of grain size with sediment transportation. At Kolhar (upstream) most of the sediments are transported in fine grain sizes (i.e., 1–10 μm) in June. A similar peak is obtained for August, about 150 km downstream at Sangam, indicating the temporal variations in sediment properties. This is simply due to the time required for the transport of sediment from one location to another (Fig. 7). Again at Sangam, the quantity of sediment transported increases in the coarser fractions (i.e., 10–100 μm) during June, which may be due to the confluence of tributaries, namely the Malaprabha and the Ghataprabha, carrying coarser particles in suspension.

At midstream (both at Kurnool and Srisailam) fine grains are abundant in June and coarse grains are abundant in August (Fig. 8). Kurnool and Srisailam are more or less in the same elevation and are made up of similar rock type (granites and gneisses). Hence, there is not much variation in the grain size with sediment transportation. However, in August at Srisailam (upstream of dams) more coarse grain particles are present essentially due to settling down of finer particles near the dam.

At the river mouth (Vijayawada) fine particles are more dominant in the sediment transportation. Coarser particles are trapped between Srisailam and Vijayawada due to dams and only fine particles are transported towards the river mouth (Fig. 9). The Bhima carries relatively more coarse grain particles, which may be due to its high altitude and its geological setting.

CONCLUSION

The sediment supply of the Krishna River, an intensively utilised river basin in southern India, is mainly due to human activities rather than as the natural consequence of geological processes. Further engineering structures (for example, the Upper Krishna Project in Karnataka, now underway) may disturb the natural geochemical processes in the river basin. The present study indicates that the Krishna River delivers annually 4.11×10^6 ton of sediment load to the Bay of Bengal at an erosion rate of 16 ton km^{-2}. It is also evident from the present study that nearly 95% of the sediment load is derived during the monsoon period, and that at the river mouth only finer particles were added to the monthly sediment load of the river owing to human interference.

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