# Mass Transport in Krishna River Basin, India.

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Abstract: Samples of water and particulate matter were collected 4 times over a three year period (1981-84) for the entire region of Krishna and its major tributaries. On the basis of our observations, average annual chemical and sediment load supplied at various parts of the basin have been computed and compared to major rivers of the world. Monthly and annual variations in mass transport as function of time and space has been observed in the river basin. Krishna river at Vijayawada (mouth of the river) delivers annually 10.4 million tonnes of dissolved load and 1.74 million tonnes of sediment load into the Bay of Bengal. 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 which trap the sediments. Sediment yields calculated for various sub-basins of Krishna river system indicate that smaller basin erode more rapidly than larger basin. The rate of sedimentation determined using pb $^{210}$ exc. technique shows high values when compared to rate of erosion. This high sedimentation rate indicates that most of the sediments are of local origin due to bank erosion and not derived by the weathering processes in the catchment area.

## INTRODUCTION

To understand the geochemical mass balance between land and ocean the estimation of masstransfer from continents to oceans are very important. Rivers are by far the most important supplier of material to the ocean system.Several attempts have recently been made to understand river transport of materials. The most important of these are by Meybeck(1976) Gibbs (1977), Martin & Meybeck (1979) and by Milliman & Meade (1983). Global estimates on fluxes given by Garrels et.al. (1975),Martin & Meybeck (1979) and Nriagu (1979) are largely based on studies of a few low sediment rivers such as the Amazon and Yukon and some large North American rivers. Asian rivers contribute more than 70% of the global sediment input to World oceans (Milliman &Meade 1983);thus any understanding of the geochemical behaviour of elements in our environment would require the study of large Asian rivers. In the Indian subcontinent, mass transfer studies have recently been initiated (e.g. Raymahasay 1970; Subramanian 1978,1979; Bikshamiah & Subramanian 1980). While

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at first approximation, the sediment transfers from non-Himalayan rivers are less than 5% of the Himalayan rivers (Subramanian 1979) from qualitative point at least, the southern non- Himalayan rivers need to be studied. Bikshamiah & Subramanian(1980) have studied the mass transfer in Godavari river and concluded that the annual mass transfer of this river is about 10% of that of the Himalayan drainage system. There is practically no information on Krishna river mass transport. Hence, an attempt has been made in this study to understand the chemical and sediment mass transfer in the Krishna and its major tributaries.

## KRISHNA RIVER BASIN

The Krishna river catchment lies between the latitudes 13 N and 19 30 N and longitudes 73 23 E and 80 30 E. The drainage basin map of krishna is shown in Fig 1. The basin has the drainage area of 2,58,945 sq.km. of which 26.8% lies in Maharashtra, 43.8% in karnataka and 29.4% in Andhra pradesh (Rao 1975). In terms of catchment area, this basin is fifth among the Indian rivers and the largest river after Godavari in southern India.The river rises in the Western Ghats from a slender spring near Mahabaleshwar in the Maharashtra state at an elevation of 1337 m, about 64 km. from Arabian Sea. After flowing 1400 km. and collecting waters from a number of tributaries Krishna becomes a mighty river and joins the Bay of Bengal. The annual discharge of the Krishna varies from 3 to 34,000 m s , with 2146 m s , as the mean discharge (Rao 1975). Throughout the river basin, maximum discharge is reported to occur in the month of August (Table 1).

The river traverses peninsular India from west to east and on its way is joined by several tributaries (Fig 1). The Tungabhadra and Bhima are the major ones. Most of the basin is semi-arid with an arid zone in the centre. Humid zones are found on the hills to the west. Rainfall in this basin is mainly due to the south-west monsoon. Except for a narrow strip along the Western Ghats and a small portion at the lower end, the Krishna basin has an average annual rainfall of less than 500 mms of which 75% occurs during the south-west monsoon.

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 4 times (April 1982; February 1984; June 1984; August 1984) to broadly cover seasonal variations. The samples collected in the months of February and April represent Dry season while in June and August represent Wet season. Fig 1A shows the location of the sampling stations.The locations were

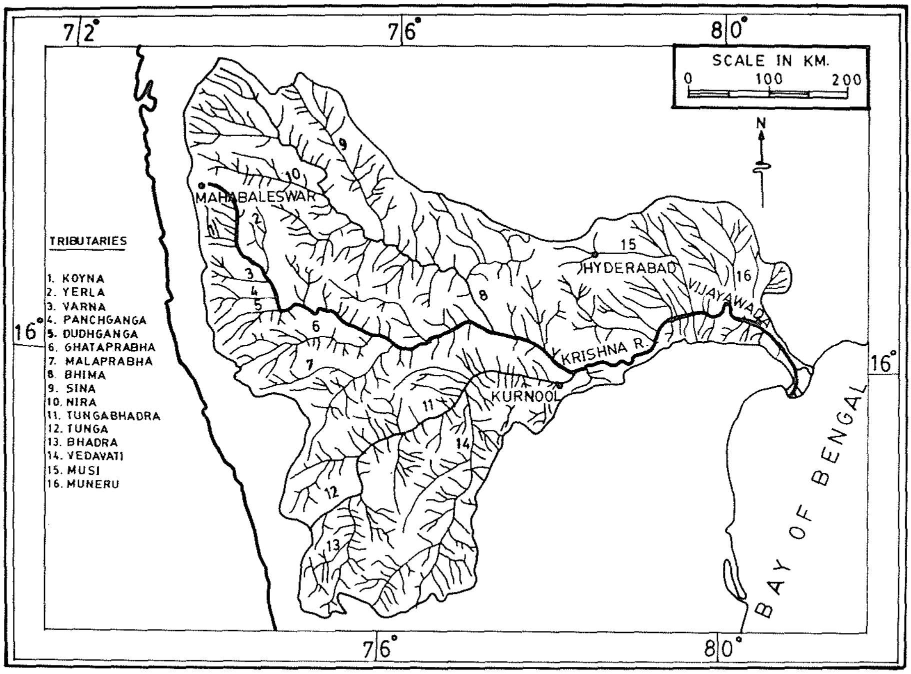


Fig 1 Drainage basin map of the Krishna river basin.

chosen so as to represent all regions of the river basin, major tributaries, their zones of mixing with the river, major urban areas, dams etc. Preservation of samples, laboratory processing and water analysis (major cations and anions) were based on standard techniques (Subramanian 1979). Discharge data for these locations during the year 1971-81 and sediment data for four locations at different months during the year 1980 were obtained from unpublished reports of the Central Water Commission, Government of India.

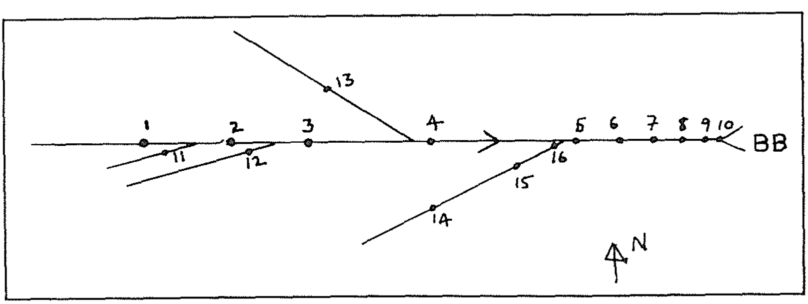


Fig 1A Flow diagram of the Krishna riverwith sampling points. Numbers 1 to 16 correspond to locationsin Table 1 colums 2 and 3. (Fig not to scale).

Table 1. Some Hydrological Characteristics of the Krishna River Basin

| Location No. | River | Site | Drainage area ($Km^2$) | Discharge in Million Cubic Meters[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Feb | April | June | August | Annual |
| 1 | Krishna | Kolhar | 5462 | 41 | 51 | 340 | 1542 | 4502 |
| 2 | Krishna | Sangam | 55150 | 82 | 17 | 941 | 6401 | 20960 |
| 3 | Krishna | Sangam | 55150 | 82 | 17 | 941 | 6401 | 20960 |
| 4 | Krishna | Raichur | 136618 | 39 | 27 | 1525 | 8883 | 34026 |
| 5 | Krishna | Kurnool | 210500 | 206 | 94 | 1538 | 11412 | 87718 |
| 6 | Krishna | Srisailam | 206041 | 268 | 146 | 893 | 11365 | 50345 |
| 7 | Krishna | Vijayawada | 251360 | 179 | 92 | 160 | 7508 | 29962 |
| 8 | Krishna | Rapalle | 251360 | 179 | 92 | 160 | 7508 | 29962 |
| 9 | Krishna | Nagaylanka | 251360 | 197 | 92 | 160 | 7508 | 29962 |
| 10 | Krishna | Nagayalanka | 251360 | 197 | 92 | 160 | 7508 | 29962 |
| 11 | Gataprabha | Bagalkot | 8610 | 33 | 7 | 121 | 1046 | 3259 |
| 12 | Malaprabha | Sangam | 11400 | 42 | 12 | 114 | 248 | 1752 |
| 13 | Bhima | Yadgir | 69863 | 69 | 19 | 351 | 2671 | 11496 |
| 14 | Tungabhadra | Hampi | 38018 | 165 | 224 | 75 | 3032 | 8448 |
| 15 | Tungabhadra | Mantralayam | 60630 | 180 | 182 | 154 | 2967 | 9215 |
| 16 | Tungabhadra | Kurnool | 67180 | 22 | 42 | 132 | 2073 | 6922 |

[1]Mean discharge for 10 years (1971-81) calculated from CWC Data.

## RESULTS AND DISCUSSION

### 1. Variation of the dissolved and suspended load :

Some of the important hydrological characteristics for the Krishna river basin are summarised in Table 1 . Table 2 and 3 summarizes the total dissolved salts (TDS), total suspended matter (TSM), P , and Electrical Conductivity (EC) values at different locations during dry and wet season. Table 3 also shows the annual discharge weighted average values calculated from the data obtained in wet and dry seasons and from the discharge values given in Table 1.After Vijayawada the EC shows very high values due to mixing of sea water. An increase in the EC reflects an increase in the ionic strength of the solution which inturn indicates an increase in TDS. Table 2 and 3 shows erratic downstream and seasonal variation of TDS and TSM. Downstream and seasonal chemical variations have been reported for a number of other rivers (e.g. Gibbs 1967; Grover 1972; Subramanian 1974; 1983).Especially for the TSM, variations are large both in space and in time. In general minima and maxima are related to the diluting and concentrating effects of tributary inflows. Besides the effect of tributaries such as agriculture, dams etc. are the suggested factors for the erratic changes of TDS and TSM.

### 2. Monthly variations of runoff and sediment transport:

Since the sediment and dissolved load carried by a river depends on discharge, monthly variations in material transport linked to fluctuations in river discharge are commonly observed for a number of rivers (Gibbs 1967; Grove 1972). Throughout the river basin, maximum discharge is reported to occur in the monsoon months. Monthly variations in runoff and sediment load are shown graphically in Fig 2 for the upstream and downstream locations of Krishna river and its tributaries during the year 1980.Both runoff and sediment load reaches their maximum during peak monsoon period in June to September at all locations. Thus the sediment transport is directly related to runoff.Runoff and sediment load reaches their peak in August. The same is true for the Godavari river basin (Bikshamiah & Subramanian 1980).

### 3. Annual Mass Transport:

Based on annual mean TDS and TSM values from this work (Table 3) and the ten years annual mean discharge (Table 1),fluxes and erosion rates have been calculated and the data are shown in Table 4. Fluxes and rates for the Krishna basin are compared to other large Indian rivers as well as to other major world rivers in Table 5. The present study indicates that the Krishna river at Vijayawada (mouth of the river) delivers 12.14 million tonnes (10.4 million tonnes of dissolved and 1.74 million tonnes of solid) of materials to the Bay of Bengal. This represents only one percent of the total mass transfer from the Indian sub-continent into the

Table 2. Dissolved and suspended load of the Krishna river and its tributaries (Dry Season)

| Location No. | April 1982 TDS (ppm) | TSM (ppm) | pH | Conductivity (µs/cm.) | February 1984 TDS (ppm) | TSM (ppm) | pH | Conductivity (µs/cm.) |
|---|---|---|---|---|---|---|---|---|
| 1 | 453 | 10 | 8.1 | 750 | 411 | 3 | 7.6 | 590 |
| 2 | 431 | 10 | 8.1 | 550 | 422 | 124 | 7.6 | 640 |
| 3 | 369 | 20 | 8.0 | 500 | 446 | 19 | 7.7 | 620 |
| 4 | 358 | 2 | 8.3 | 550 | 747 | 31 | 7.6 | 1350 |
| 5 | 524 | 92 | 7.8 | 800 | 581 | 6 | 7.9 | 830 |
| 6 | 475 | 650 | 7.8 | 800 | 451 | 9 | 7.8 | 700 |
| 7 | 319 | 30 | 7.9 | 350 | 360 | 3 | 7.6 | 500 |
| 8 | 693 | 10 | 7.9 | 1100 | 389 | 14 | 7.6 | 620 |
| 9 | 658 | 2 | 7.9 | 900 | 683 | 4 | 7.5 | 1450 |
| 10 | 3675 | 2 | 7.9 | 5000 | 726 | 8 | 7.9 | 1500 |
| 11 | 387 | 9 | 8.0 | 450 | 386 | 15 | 7.8 | 560 |
| 12 | 393 | 16 | 8.0 | 550 | 424 | 84 | 7.8 | 670 |
| 13 | 459 | 2 | 8.0 | 900 | 555 | 21 | 7.9 | 720 |
| 14 | 317 | 10 | 7.6 | 300 | 224 | 15 | 7.2 | 260 |
| 15 | 408 | 10 | 8.0 | 600 | 526 | 11 | 7.9 | 740 |
| 16 | 508 | 120 | 8.0 | 800 | 434 | 10 | 7.8 | 890 |

Table 3 Dissolved and suspended load of Krishna river and its tributaries (wet season and annual discharge weighted average)

| | June 1984 | | | | August 1984 | | | | Annual | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Loc. | TDS (ppm) | TSM | $p^H$ | cond. (μs/cm) | TDS (ppm) | TSM | $p^H$ | cond. (μs/cm) | TDS (ppm) | TSM | $p^H$ | cond. (μs/cm) |
| 1 | 569 | 156 | 7.5 | 940 | 192 | 106 | 7.2 | 120 | 268 | 110 | 7.3 | 287 |
| 2 | 607 | 1047 | 7.8 | 1080 | 235 | 170 | 7.2 | 120 | 285 | 280 | 7.3 | 248 |
| 3 | 453 | 1665 | 7.8 | 690 | 341 | 152 | 7.7 | 400 | 356 | 342 | 7.7 | 439 |
| 4 | 666 | 179 | 7.9 | 1180 | 413 | 484 | 7.8 | 380 | 451 | 437 | 7.8 | 501 |
| 5 | 645 | 91 | 8.0 | 1150 | 313 | 210 | 7.5 | 240 | 357 | 192 | 7.6 | 359 |
| 6 | 474 | 75 | 8.0 | 810 | 303 | 235 | 7.6 | 260 | 320 | 224 | 7.6 | 314 |
| 7 | 353 | 49 | 8.2 | 540 | 347 | 60 | 7.5 | 430 | 347 | 58 | 7.5 | 433 |
| 8 | 374 | 56 | 8.0 | 590 | 398 | 74 | 7.7 | 410 | 401 | 71 | 7.7 | 427 |
| 9 | 366 | 24 | 8.1 | 570 | 383 | 31 | 7.8 | 410 | 393 | 30 | 7.8 | 445 |
| 10 | 606 | 37 | 8.0 | 1250 | 384 | 66 | 7.8 | 450 | 435 | 63 | 7.8 | 545 |
| 11 | 504 | 119 | 7.7 | 800 | 265 | 52 | 7.4 | 150 | 293 | 57 | 7.4 | 228 |
| 12 | 436 | 1380 | 7.7 | 700 | 438 | 73 | 7.8 | 520 | 435 | 431 | 7.8 | 585 |
| 13 | 701 | 196 | 7.7 | 980 | 489 | 512 | 7.7 | 400 | 514 | 462 | 7.7 | 476 |
| 14 | 421 | 145 | 8.0 | 600 | 206 | 50 | 7.3 | 110 | 219 | 48 | 7.3 | 140 |
| 15 | 550 | 98 | 8.0 | 910 | 324 | 102 | 7.3 | 250 | 349 | 92 | 7.4 | 323 |
| 16 | 607 | 198 | 8.1 | 900 | 320 | 268 | 7.4 | 220 | 341 | 259 | 7.5 | 277 |

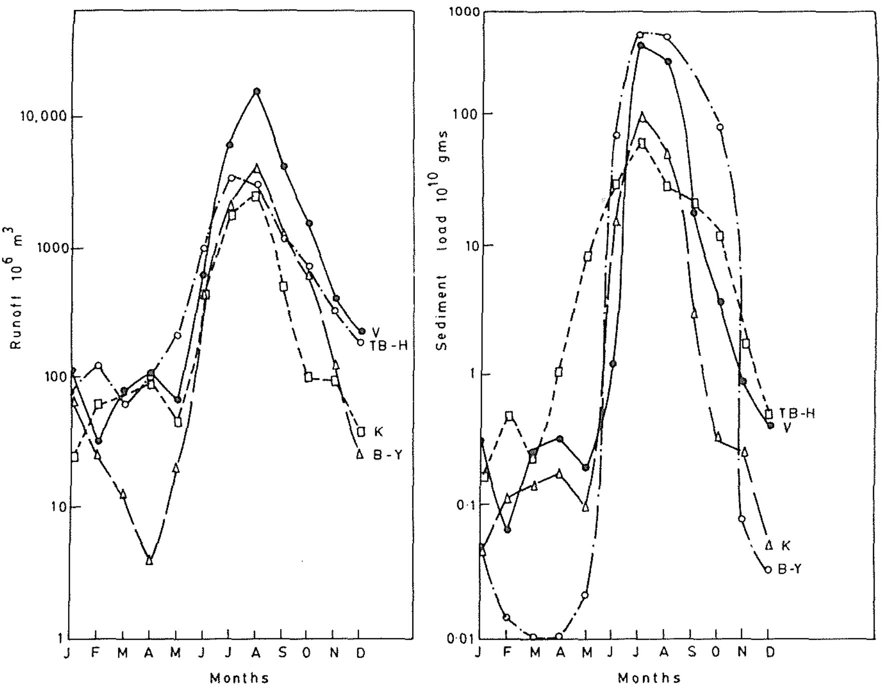


Fig 2 Variation of runoff and sediment load with months for the year 1980. K- Karad (upstream) V-Vijayawada (downstream) TB-H- Tungaghadra (Harahalli) B-Y-Bhima (yadgir)

world oceans (Subramanian 1979). Within the basin the various fluxes and rates indicate a lack of uniformity, primarily due to different sub-basin geology, elevation and various degrees of human impact. The dissolved transport gradually increases towards downstream from Kolhar to Kurnool (Table 4). After entering into the sedimentary terrain located in the lower part of the basin (1100 km from the source) there is a sudden depletion of dissolved load at Srisailam. This may be due to the adsorption from the dissolved to the solid phase. However, this process need to substantiated by careful study of the sediment chemistry. The annual sediment transport at the river mouth is small when compare to upstream. For example, sediment transportation at Vijayawada is one seventh of those observed upstream (Table 4). Between Srisailam and Vijayawada there are two major dams. Most of the sediment settle down in this area. Hence part of the sediment yield from the basin does not reach the river mouth. In calculating erosion rates, several workers (e.g. Holeman 1968; Meybeck 1976) have used sediment data from river mouth stations. The present study indicates that due to the presence of dams, the total sediment yield of the basin does not reach the river mouth. Hence continent-ocean sediment balance studies should not be based on such data. The Bhima is the main contributor of sediments to the Krishna. The

Table 4 Mass transport of the Krishna river and its tributaries:.

| River site | chemical load | sediment load | Total load | chemical erosion | sediment erosion | Total erosion |
|---|---|---|---|---|---|---|
| | (million tonnes/year) | | | (tonnes/km$^2$/year) | | |
| Krishna at: | | | | | | |
| Kolhar | 1.21 | 0.50 | 1.71 | 221 | 91 | 312 |
| Sangam | 7.45 | 7.16 | 14.61 | 135 | 130 | 265 |
| Raichur | 15.34 | 14.86 | 30.2 | 112 | 109 | 221 |
| Kurnool | 31.33 | 16.86 | 48.19 | 149 | 80 | 229 |
| Srisailam | 16.12 | 11.26 | 27.38 | 78 | 55 | 133 |
| Vijayawada | 10.40 | 1.74 | 12.14 | 41 | 7 | 48 |
| Tributaries: | | | | | | |
| Gataprabha | 0.95 | 0.19 | 1.14 | 111 | 22 | 133 |
| Malaprabha | 0.76 | 0.75 | 1.51 | 67 | 66 | 133 |
| Bhima | 5.91 | 5.31 | 11.22 | 85 | 76 | 161 |
| Tungabhadra | 3.21 | 0.85 | 4.06 | 53 | 14 | 67 |

Table —5 Erosion rates of some important rivers in the world

| River | Discharge $10^9\ m^3\ yr^{-1}$ | Drainage Area $10^3 Km^2$ | Chemical Load (Million Tonnes/yr) | Sediment Load (Million Tonnes/yr) | Total Load (Million Tonnes/yr) | Chemical Erosion Rate (Tonnes/$Km^2$/yr) | Sediment Erosion Rate (Tonnes/$Km^2$/yr) | Total Erosion Rate (Tonnes/$Km^2$/yr) | Sediment / Chemical |
|---|---|---|---|---|---|---|---|---|---|
| Krishna | 30 | 251 | 10.4 | 1.74 | 12.12 | 41 | 7 | 48 | 0.17 |
| Godavari | 92 | 310 | 17 | 170 | 187 | 55 | 555 | 610 | 10 |
| Cauvery | 21 | 88 | 3.5 | 0.04 | 3.54 | 40 | 0.5 | 40.5 | 0.01 |
| Brahmaputra | 510 | 580 | 51 | 597 | 648 | 88 | 865 | 953 | 9.8 |
| Ganges | 493 | 750 | 84 | 329 | 413 | 111 | 438 | 549 | 3.9 |
| Huang-He | 48 | 745 | 22 | 1080 | 1102 | 30 | 1402 | 1432 | 46.7 |
| Yangtze | 1063 | 1950 | 226 | 478 | 704 | 116 | 246 | 362 | 2.1 |
| Amazon | 5500 | 6300 | 287 | 900 | 1187 | 46 | 146 | 192 | 3.1 |
| Irrawady | 422 | 430 | 90 | 285 | 375 | 211 | 662 | 873 | 3.1 |
| Magdalena | 236 | 240 | 28 | 220 | 248 | 117 | 916 | 1033 | 7.8 |
| Mississippi | 580 | 3267 | 131 | 210 | 341 | 40 | 64 | 104 | 1.6 |
| Orinoco | 946 | 950 | 50 | 210 | 260 | 52 | 212 | 264 | 4.0 |
| Mekong | 666 | 795 | 59 | 160 | 219 | 74 | 200 | 274 | 2.7 |
| World Average | 31400 | 101000 (88600)* | 3600 | 13505 | 17105 | 35 | 150 | 185 | 4.3 |

Note: * Milliman and Meade (1983) calculated world sediment load based on 88600 $10^3\ Km^2$
Krishna - present work; Erosion rates of other rivers were compiled from different sources:- Biksham (1985); Subramanian et.al. (1985); Subramanian (1979); Abbas & Subramanian (1984); Milliman and Meade (1983); Hu-Minghui et.al. (1982); Sarin & Krishnaswami (1984); Meybeck (1976); Meybeck (1979); Gibbs (1972).

Table 6 Sedimentation and erosion rates in Krishna river basin

| Core (Location) | Sedimentation Rate | Sediment Flux | Erosion Rate* | |
|---|---|---|---|---|
| | mm $yr^{-1}$ | gm $cm^{-2}$ $yr^{-1}$ | $10^{-4}$gm $cm^{-2}yr^{-1}$ | mm $yr^{-1}$ |
| Krishna-Kolhar | 3.5 | 0.308 | 327 | 0.372 |
| Krishna-Raichur | 3.8 | 0.334 | 322 | 0.366 |
| Krishna-Vijayawada | 3.9 | 0.343 | 16 | 0.018 |
| Krishna-Repalle | 11.0 | 0.968 | 9 | 0.010 |
| Tungabhadra-Hospet | 5.3 | 0.466 | 99 | 0.113 |

* Average erosion rate for ten years (1971-1981) based on the particulate load from CWC data.

Bhima predominantly drains an area of partially weathered Deccan Trap from which sediment particles can be easily released by physical weathering.

4. Erosion Rates:

The annual erosion rate varies from a low value of 48 tonnes/sq. km for Vijayawada downstream to a high value of 312 tonnes/sq.km for Kolhar upstream.The sediment erosion rate for the entire Krishna river basin is low when compare to chemical erosion rate (Table 4). Gibbs (1981) reported that physical erosion is dominant in Asian rivers. But the present study indicates that the intensively utilized medium size river basins in India like those of the Krishna and the Cauvery are highly chemically active compared to other world major rivers (Table 5). Rates of sedimentation determined in Krishna river basin using pb-$^{210}$ exc technique(Ramesh et.al. 1986) shows high values when compared to rates of erosion (Table 6). The sedimentation rate varies to a factor of 10 for the cores from the upstream (Kolhar) and midstream (Raichur) whereas the cores from downstream and Tungabhadra show large variations.The increase in sedimentation rate may be due to local activities such as agriculture, deforestation, grazing, road and building constructions which locally release sediments inturn accelrating the rate. The relative effects of these factors are at present not quantitatively estimated.

The relative proportion of chemical and physical erosion in the Indian rivers has been briefly discussed by earlier workers (Bikshamiah & Subramanian 1980; Subramanian & Dalavi 1978). Judson and Ritter (1964) observed a negative relationship between these two processes for North American rivers. Data for the Krishna river system plotted in Fig 3 indicate a positive relationship. In this respect, the Krishna may be considered to simulate continent-wide global behaviour. Except Krishna and Cauvery all the major Indian

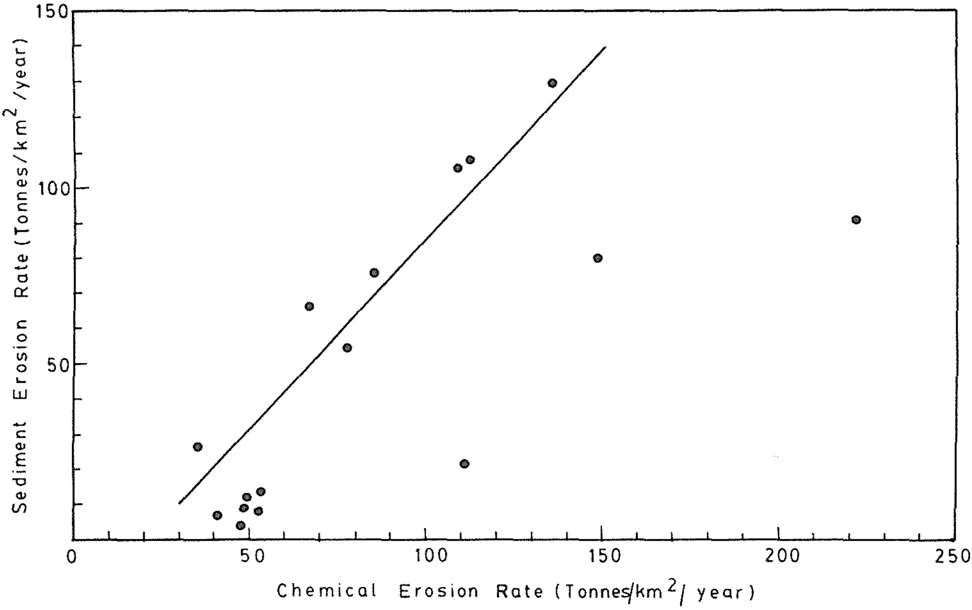


Fig 3 Sediment erosion/chemical erosion relationship for the Krishna river basin.

and world rivers are mechanically more active, while Peninsular rivers particularly Krishna and Cauvery are chemically more active.

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