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Preliminary studies on the geochemistry of the Cauvery river basin

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Abstract. Samples of water and sediments were collected over a three year period from the entire region of Cauvery river basin excluding the estuary. On the basis of our observations, we have calculated the average composition of the Cauvery river at several locations from the catchment to the river mouth, the downstream profile of sediment load, annual erosion rates, solute and sediment fluxes and have predicted on long term changes. The sediment chemistry was determined by x-ray fluorescence (XRF) technique, and calculated mean compositions of the Cauvery and its tributary bed and the suspended sediment were compared to those of world average river sediments. Downstream profiles of some of the elements appear to be controlled by size and mineralogical characteristics besides local factors specific to the location of the samples. Interelemental relationships indicated good correlation among the transition elements indicating their co-genetic behaviour within the drainage basin.

Keywords. Geochemistry; Cauvery river basin; sediment load; annual erosion rates; x-ray fluorescence; co-genetic behaviour.

1. Introduction

Geochemical cycling of elements is receiving wide attention due to the need for understanding the pathways of pollutants through our present environment. River processes form a major link in the geochemical cycle. Several attempts have recently been made to understand river transport of materials. The most important of these are by Gibbs (1977), Martin and Meybeck (1979) and by Milliman and Meade (1983). Global estimates on fluxes given by Garrells *et al* (1975), Martin and 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 and Meade 1983); thus any understanding of the geochemical behaviour of elements in our environment would require the study of large Asian rivers. With this objective in mind, the authors have been studying the large rivers of the Indian sub-continent. The present report is based on preliminary studies on the geochemistry of the entire Cauvery river basin.

2. The Cauvery river basin

The cauvery river is the eighth largest river (in terms of discharge) in the Indian subcontinent. It has a drainage area of about 90,000 km^2 covering a distance of 800 km, from Coorg in the Western Ghats to the river mouth at the Bay of Bengal. Hemavati, Kabini, Bhavani and Amaravati are the major tributaries. Some of the important hydrological data for the Cauvery river basin are summarised in table 1.

Table 1. Some hydrological characteristics of the Cauvery river basin

River site	Annual run off[a] (million m^3/yr)	Drainage area[a] (km^2)	Mean discharge[b] (m^3/sec)	TDS[c] (ppm)	TSM[c] ppm
Hemavathi	2520	5200	80	95–221	1–30
Krishnaraja sagar	6200	—	197	110–167	7–45
Kabini	2600	6700	83	105–246	5–8
Mettur dam	14380	—	457	83–238	1–5
Bhavani	3090	7144	98	115–337	10–50
Amaravati	1080	5200	34	128–617	20–35
Upper Anicut	18970	—	602	138–321	15–50
Lower Anicut	20950	87900	665	125–274	1–30

[a]Annual run-off and drainage area (from Rao 1975); [b]calculated from annual run-off: [c]range of values; TDS—total dissolved solids.

While the upper reaches of the river basin drain predominently the Precambrian shield rocks, the downstream regions lie on the Tertiary sedimentary rocks and Plio-Pleistocene sediments. The upper reaches cover an elevated (topographic high) plateau and the river drops its height sharply by more than 200 metres into the plains after the Sivasamudram falls. Boreholes near the river mouth indicates cretaceous and probably upper Gondwana sediments, below 3000 m (Wadia 1975).

The Cauvery is one of the most intensively utilised river basins in India. Since most of the water is withdrawn for irrigation at several stations along its course, several distributaries form a net work of broad (about 100 km) and shallow delta at the river mouth.

3. Methodology

Samples of river water, suspended and bed sediments were collected at 16 locations along the river as well as the tributaries. The locations were chosen so to represent all the regions of the river basin, major urban areas, dams etc. Between 1979 and 1982, samples were collected 4 times (October 15–31, 1979; December 1–25, 1980; May 17–June 5, 1981; August 2–31, 1982) to broadly cover seasonal variations (summer, monsoon, post-monsoon and winter). Figure 1 shows the flow pattern and sample locations in the river basin. While measurement of suspended sediments and water chemical analysis were carried out on all samples in each batch collected, suspended sediment mineralogy, bed sediment size studies and chemistry of bed and suspended sediments were carried out on limited samples only.

Standard analytical procedures (atomic absorption spectrophotometer-cations; calorimetry-anions and silica; pH-ion analyser for pH, Cl^- and F^-) were adopted for water chemistry and sediment filtration. Suspended sediments were filtered with a Millipore filter (0·45 micron). Grain size analysis of bed sediments was done by the sieving technique and the chemistry of bed and suspended sediments was done by x-ray fluorescence technique (details reported in Van Grieken *et al* 1980). For cation analysis, the analytical precision was better than 5 %; for anions including fluoride, it was 9 %.

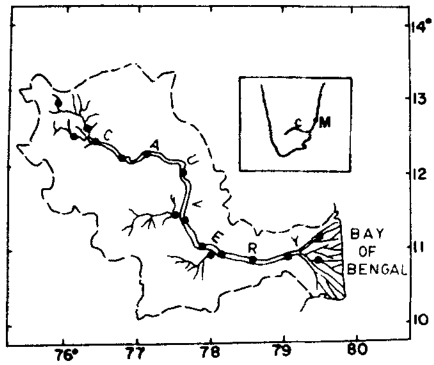

Figure 1. Drainage basin map of Cauvery river basin with sampling locations.

For sediment analysis by XRF, IAEA standard soil-5 was also run, table 2 gives observed and recommended values for the standard.

Discharge data for the Cauvery river at important locations were obtained from unpublished reports of the Irrigation and Water Resources sections of the Karnataka and Tamil Nadu Governments.

4. Results and discussion

4.1 *Chemical and suspended load*

Among the 16 sampling locations, eight are on either side of the junctions of the tributaries with the Cauvery. The average chemical composition of various tributaries and of the Cauvery river at important locations in the Cauvery and her tributaries are summarized in table 3. The average values were calculated from the data obtained in

Table 2. Analysis ($\mu g g^{-1}$) of IAEA soil 5 standard by XRF

Element	Average value*	Standard deviation per	Standard deviation on	Recommended value
Mg	16,000	1,800	780	15,000
Al	73,100	1,800	800	81,900 ± 2,800
Si	247,000	5,000	2,000	330,000
K	15,400	300	140	18,600 ± 1,500
Ca	22,100	900	410	22,000
V	195	15	7	151
Cr	28	6	2	28 ± 3
Mn	908	47	21	852 ± 37
Fe	43,600	2,200	980	44,500 ± 1,900
Co	30	—	—	15 ± 1
Ni	10	1	0	13
Cu	88	5	2	77 ± 5
Zn	379	19	9	368 ± 8

*Average of six measurements.

Table 3. Average[a] chemical composition of Cauvery river water.

Location	pH	Conductivity (ms/cm)	HCO_3^{-1}	SO_4^{-2}	Cl^{-1}	$H_4SiO_4^0$	Na^+	K^+	Ca^{+2}	Mg^{+2}	TDS
			ppm								
Krishnaraja sagar	8·1	0·23	50	8	11	7	23	2	7	12	120
Sivasamudram falls	8·6	0·22	38	34	11	7	25	1	18	14	130
Mettur dam	8·3	0·27	52	44	17	6	36	2	19	11	160
Grand Anicut	8·1	0·30	50	51	13	7	38	2	13	12	170
Thanjavur	8·4	0·32	51	29	9	9	39	2	16	16	180
Hemavati	8·3	0·26	32	8	8	9	25	2	19	12	120
Kabini	7·6	0·21	50	29	13	6	23	1	11	18	150
Bhavani	8·4	0·41	55	60	15	9	43	4	16	20	220
Amaravati	8·5	0·85	102	87	65	16	16	7	20	25	300

[a]Discharge weighted

four seasons. The upstream regions of the Cauvery as well as its tributaries in this region have TDS (total dissolved solids) values less than the corresponding downstream values. The two distinct regions of the basins have geological as well as geographical differences. Marginal increase of TDS downstream may be due to two reasons: (a) highly weatherable tertiary sediments; (b) very dense population and hence increasing impact of use of water on water quality. The bulk of the TDS values is made up of alkalinity and some of the tributaries, such as Amaravati, carry a large SO_4^{-2} load as well. Most of the SO_4^{-2} is likely to be of secondary source, as was reported for the Ganges river water by Handa (1972).

Figure 2 shows an example of the downstream profile in the Cauvery river basin. Conductivity is used here to illustrate changes in the dissolved constituents. Similar downstream changes in the profile of suspended sediments are also shown. Unlike major Indian rivers such as Ganges (Subramanian 1979), there are several dams and reservoirs along the course of the Cauvery. The suspended sediments settle in these regions; as a result, TSM (total suspended matter) profile is generally negative downstream. There is an abrupt change in the basin bed topography from high plateau to flat plain at Sivasamudram falls and the resultant force of water causes resuspension of bed sediments. The TSM profile shows a small increase in this region. In addition, the suspended waste materials brought by tributary Amaravati adds upto the TSM load after the tributary junction.

The mean composition of the tributaries reflect the sub-basin geology, and in the Amaravati region the varying levels of local human influences on water quality. Though

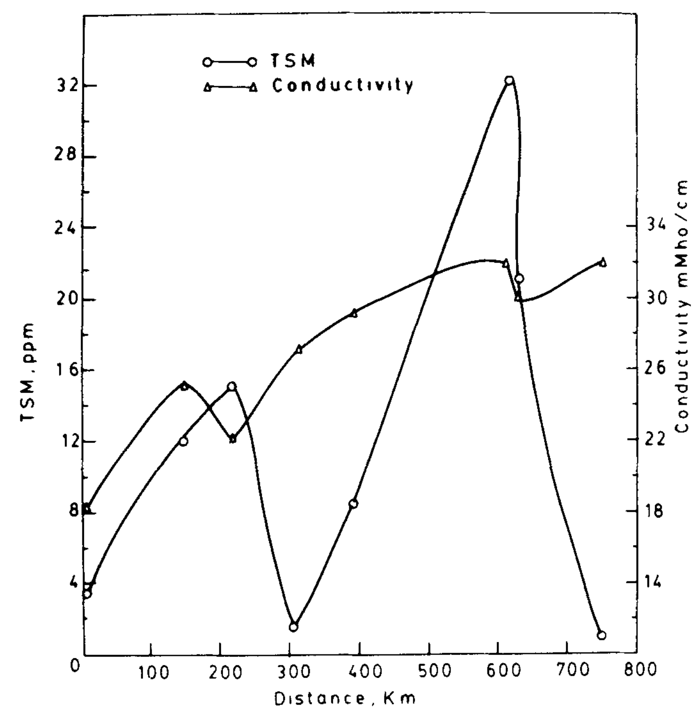

Figure 2. Downstream profile for conductivity and total suspended matter (TSM) in the Cauvery river basin.

no corrections have been made for atmospheric recycling, the chemical load and composition of the Cauvery at its mouth is close to that of Indian average (Subramanian 1979) which is slightly higher than the world average of Livingstone (1963).

4.2 *Erosion rates*

Based on mean TDS, TSM values from this work (table 1) and the annual run off at several locations (Rao 1975), fluxes, erosion rates and other denudation parameters have been calculated. These data are presented in table 4. For comparison, the average values for the Indian subcontinent from Subramanian (1978), and the average for the continents are shown. The only significant contribution of the Cauvery basin to the subcontinent wide process is in terms of total chemical load and the chemical erosion rates (CER) (1·6% the chemical load and 25% the CER of the Indian average). Total fluxes and erosion rates for the Indian subcontinent are of course very high, relative to the global averages, due to the extreme levels of sediment loads in the Ganges-Brahmaputra system (Milliman and Meade 1983; Subramanian 1979).

Within the Cauvery basin, various fluxes and rates indicate no uniformity, primarily due to different sub-basin geology, elevation and various degrees of human impact on water chemistry. Since the chemical fluxes and rates are based on observed TDS values, corrections for atmospheric recycling and substraction of urban and agricultural drain-off contribution will yield the component of TDS truly derived by chemical weathering. At present sufficient data are not available to effect these corrections. Hence table 4 values perhaps show the upper limit. In similar studies on Chinese rivers, Hui Ming Hui *et al* (1982) also observed high TDS values without correction for precipitation chemistry and pollution components. On the other hand, Stallard and Edmond (1982) improved on Gibbs (1977) data for the Amazon after extensive monitoring of precipitation chemistry over the Amazon basin. Thus, our fluxes and rates though averaged over a 3 year period may not truely reflect natural geochemical processes in the Cauvery river basin.

4.3 *Bed sediment*

Size analysis of bed sediments indicate that fractions greater than 1000 μm are the important size population, in the river basin. Dominance of quartz is consistent with the coarseness of the bed sediments. Sand fraction is generally dominent except near the river mouth where silt becomes significant. Clays fractions which dominate the particulates (Subramanian 1980) were generally absent in the bed sediments. Within the sand fraction, distribution of individual size population varies longitudinally but not systematically. Figure 3 shows the general trend in the downstream profile of mean size (graphic mean) and organic matter content. The maxima and minima in the plot generally correspond to either a reservoir region or tributary. The upstream region (above Sivasamudram falls) has sediments (dominant population above 1000 μm) which are coarser relative to the downstream region (river mouth area). Godavari and Krishna sediment have size population in the silt-clay range (Naidu 1966; Subramanian 1982). On the other hand, upper regions of Ganges and some of her tributaries have

Table 4. Erosion rates in the Cauvery river basin.

River site	Chemical load	Sediment load 10^6 kg/yr	Total load	CER 10^4 kg km^2/yr	SER	TER	Decrease in mm/1000 yr	Time to MSL (million years)
Hemavati	330	50	335	6·4	0·1	6·5	25	60
Krishnaraja sagar[a]	760	75	835	—	—	—	—	
Kabini	380	15	395	5·7	0·2	5·9	22	46
Mettur dam[a]	2600	43	2643	—	—	—	—	
Bhavani	670	37	707	9·4	0·5	9·9	37	20
Amaravati	250	33	283	4·8	0·7	5·5	21	13
Lower Anicut	3500	42	3542	4·0	0·1	4·1	15	61
India average[b]	$2·2 \times 10^5$	$1·2 \times 10^6$	$1·4 \times 10^6$	8·6	46·8	55·4	210	5
World average	390×10^{10}	1830×10^{10}	2220×10^{10}	2·3	10·8	13·1		

[a]Reservoir/dam region; CER, SER, TER-chemical, sediment and total erosion rates respectively; MSL—mean sea level; [b]From Subramanian (1978).

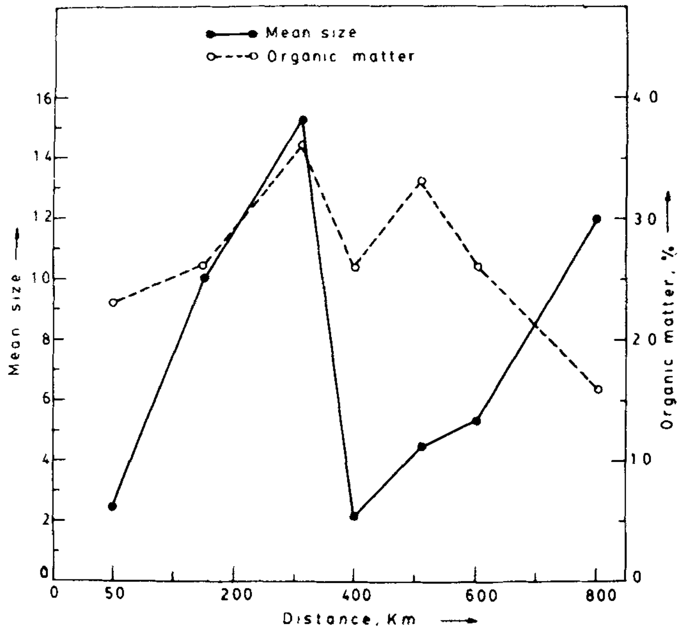

Figure 3. Downstream profile in mean grain size (graphic mean expressed in Phi units) ($\phi = -\log_2 D_{mm}$ where D_{mm} is diameter in mm) and organic matter content in the bed sediments.

generally coarse (sand) bed sediments (Singh 1974). Physical weathering is not very efficient in the Cauvery river basin (chemical/physical ratio is about 40, see table 3). In addition, several dams in the river arrest the process of abrasion so that the sediment grains remain in similar size classes released during the initial weathering process.

4.4 *Sediment chemistry*

Table 5 summarises the chemical composition of bed sediments from the Cauvery basin. There are no earlier published reports on the chemistry of Cauvery river sediments. However, for other river basins in India, partial sediment chemistry have been reported; Borole *et al* (1982) for Narmada and Tapti, Sarin *et al* (1979) for river mouth sediments of Krishna, Godavari and Ganga, Handa (1972) for Ganga at Allahabad; and Subramanian *et al* (1985) for the sub-continent as a whole. The Cauvery bed sediments have 50% more Si than the world average sediments (Si = 28·5%, Cauvery mean Si = 41·9%) of Martin and Meybeck (1979) because of the dominance of quartz in the bed load. As a result, other elements are depleted in the Cauvery bed sediments relative to the world average. Individual tributaries show wide variation in their chemistry. All of them differ from the main Cauvery itself. The tributaries drain a wide variety of geological terrain; for example, the Bhavani drains unconsolidated sediments and the hill slopes of the intensively cultivated Nilgiris and shows higher levels of hydrogenous elements such as Fe, Mn and Ni relative to the Cauvery river.

The chemistry of suspended sediments differ from that of the bed sediments in the Cauvery basin. Table 6 summarises the data on suspended sediments. The suspensions

Table 5. Chemical composition of bed sediments in the Cauvery river basin

Element	*N*	*H* 6	*K* 6	*B* 6	*A* 6	*C* 31
Mg		9600	8100	13000	10000	8100
Al		52100	35400	53000	61600	37600
Si		353000	344000	319000	336000	410000
K		18300	5350	7700	17400	8610
Ca		8740	7920	14600	15300	6290
Ti		1080	6880	4500	2010	2750
V		35	95	145	75	74
Cr		98	180	130	49	54
Mn		204	360	535	184	212
Fe		7090	17800	32600	11800	12600
Co		10	19	22	16	15
Ni		28	31	35	12	12
Cu		4	9	12	3	3
Zn		9	17	44	14	13
Rb		74	22	28	50	29
Sr		239	245	317	624	231
Pb		20	6	12	19	7

All values in μg/gm; *N* = number of samples; *H* = Hemavati; *K* = Kabini; *B* = Bhavani; *A* = Amaravati; *C* = Cauvery basin as a whole

Table 6. Heavy metals concentration in the suspended sediments of the Cauvery river basin

Element	*N*	*H* 6	*K* 6	*B* 6	*A* 6	*C*[a] 31
Ti		51400	9300	6000	5100	3200
V		3400	800	400	300	300
Cr		5600	670	210	200	150
Mn		46000	24500	4600	1900	1300
Fe		91100	21000	10200	86000	62000
Co		1100	280	200	150	100
Ni		3500	500	230	150	150
Cu		400	420	100	100	60
Zn		4500	4200	2900	450	500
Pb		450	400	200	80	40

[a]Abbreviations as in table 5; All values in μg/gm

are enriched in Fe, Mn and other transition elements relative to the bed sediments. Fe content of Cauvery particulates (6·2% average of 31 samples) compare with the Fe levels reported for Krishna (Fe = 6·9%) and Godavari (Fe = 7·23%) sediments by Sarin *et al* (1982). Similarly, results for other transition elements, such as Cr, Mn, Co, Ni, Cu and Mn for Cauvery particulates agree with those of Godavari and Krishna. The mean value for heavy metals in the Cauvery particulates exceed those of world average of Martin and Meybeck (1979). Several authors (Borole *et al* 1982; Gibbs 1977; Martin *et al* 1971; Turekian and Scott 1967) have observed varying levels of enrichments of heavy metals in river particulates similar to the Cauvery river system. Individual tributaries of the Cauvery have their own distinct particulate chemistry. For example, tributary Hemavati has its catchment covering parts of the Kudremukh iron-formation and the iron contents of particulates is very high (9·11 % mean of six samples); on the other hand, Amaravati drains an area of dense population, intensive cultivation and a large number of electroplating and leather industries. Hence in this case the high Fe-levels (8·6 %, mean of six samples) do not reflect the true natural geochemical background.

Figures 4a and b show the longitudinal profile of Fe as well as the Fe/Al ratio in the bed and suspended sediments. In both cases, Fe levels (figure 4a) in the upstream region (before Sivasamudram falls) differ from those in the downstream region. On the other hand, variation in the Fe/Al ratio downstream (figure 4b) was found to be erratic for particulates and systematic for bed sediments. Because of contribution from the upstream tributory Hemavati, both the Fe content and the Fe/Al ratio in the particulate are initially high. Due to deposition (as a result of reservoir/dam regions) of suspended

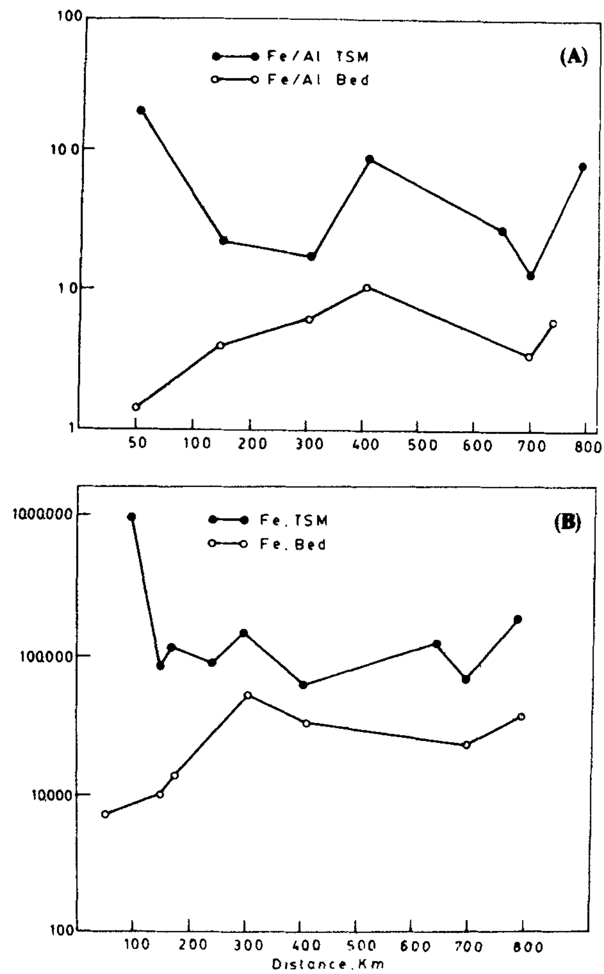

Figure 4. Downstream profile in the Fe content (A) of suspended sediments and bed sediments, and (B) the respective Fe/Al ratios. Fe values are in ppm.

Table 7. Correlation matrix for elemental analysis of bed sediments.

Elements	Al	Mg	Si	K	Ca	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
Al	1												
Mg	0·30	1											
Si	−0·51	−0·73	1										
K	−0·09	−0·19	0·45	1									
Ca	0·20	0·92	−0·80	−0·23	1								
V	0·22	0·76	−0·73	−0·19	0·83	1							
Cr	0·26	0·52	−0·41	0·02	0·36	0·53	1						
Mn	0·19	0·88	−0·78	−0·24	0·87	0·92	0·57	1					
Fe	0·35	0·84	−0·79	−0·28	0·81	0·92	0·66	0·96	1				
Co	0·24	0·89	−0·81	−0·32	0·89	0·84	0·63	0·93	0·93	1			
Ni	0·38	0·70	−0·57	−0·22	0·51	0·53	0·91	0·63	0·71	0·73	1		
Cu	0·29	0·80	−0·77	−0·29	0·79	0·81	0·72	0·84	0·87	0·88	0·79	1	
Zn	0·15	0·50	−0·57	−0·34	0·48	0·56	0·50	0·61	0·65	0·64	0·61	0·70	1

sediments, Fe as well as Fe/Al ratio in bed sediments increase downstream. Forstner and Whittman (1981) have compiled several case studies where levels of Fe and other transition element varied longitudinally in diverse aquatic environments.

Interelemental correlation was attempted for some of the transition elements. Table 7 shows the correlation matrix for bed sediments. All the elements showed good correlation with each other. In similar analysis of data for the particulates, the correlation was found to be 0·90 or above for all the element pairs.

5. Summary

The water chemistry of Cauvery river is similar to that of average river water from the Indian subcontinent. Individual sub-basins as well as regions of urban population show variations compared to the main river. Chemical weathering in the Cauvery basin is very significant and compared to other river basins, solute erosion rates are high. The bed sediments are dominated by sand size fractions and quartz.

The chemistry of bed sediments differ from the world average river sediments due to the dominance of high silica minerals (quartz) in the bed load. On the other hand, the very fine particulates show enrichment of heavy metals relative to the world average. Transition elements correlate very well with each other in suspended as well as bed sediments.

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