

# Heavy metals partitioning in sediments of the Kabini River in South India

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**Abstract** Cu, Cr, Fe, Mn, Ni, Pb, and Zn in the sediments of the Kabini River, Karnataka, India was studied to determine the association of metal with various geochemical phases by sequential extraction. The variations of heavy metal concentration depend on the lithology of the river basin and partly on anthropogenic activities. The Kabini River sediments are dominated by Sargur supracrustals with amphibolites, gneisses, carbonates, and ultrabasic rocks weathering into gneissic and serpentine soils carrying a natural load of cationic heavy metals. The source of heavy metals in the Kabini river-bed sediments is normally envisaged as additional inputs from anthropogenic over and above natural and lithogenic sources. Geochemical study indicates the metals under study were present mostly in the least mobilizable fraction in the overlying water and it is concluded that heavy metals in these sediments are to a great extent derived from multisource anthropogenic inputs besides geochemical background contributions. The results show that lead and chromium have higher potential for mobilization from the sediment due to higher concentration at the exchangeable ion and sulfide ion bounded, also Cu and Pb have the greatest percentage of carbonate fraction, it means that the study area received inputs from urban and industrial effluents.

Association of the Fe with organic matter fraction can be explained by the high affinity of these elements for the humic substances. Further, Zn and Ni reveal a significant enrichment in sediment and it is due to release of industrial wastewater into the river. These trace metals are possible contaminants to enter into aquatic and food chain.

**Keywords** Geochemistry · Heavy metals · Kabini River · Sequential extraction

## Introduction

Sediments function as sinks for various pollutants such as heavy metals and play a significant role in the remobilization of contaminants in the aquatic systems under favorable conditions. Such potential of sediment for being a sink as well as a source of contaminant can make sediment chemistry and toxicity key components of the quality of aquatic system. This could be particularly useful to investigate large riverine environments where the aqueous concentrations of pollutants are frequently close to the detection limits of chemical and toxicological methods. On the other hand, the ability of sediments to adsorb organic and inorganic contaminants makes sediment analysis a valuable tool to assess and monitor water quality and track contaminant transport in fluvial realms and mobilization in marine environments. Besides, chemical analysis of the natural matrices such as water,

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suspended particulate matter, and sediment is the most direct approach to reveal the heavy metal pollution status in the components of the environment, unless information on the extent of transfer of toxic metals on to the matrices of living beings an integrated multi-matrix analytical data is made available.

Evaluated heavy metals concentrations in river systems are often considered as indicators of anthropogenic influence and they are a risk to the natural environment. Therefore, it needs to assess and track the concentration of these heavy metals. The assessment and the effects of sediment contamination can review through the geochemical partitioning of trace metals in sediment–water interface (Lu and Allen 2001).

The discharge of heavy metals from sediments into the water body will depend on the speciation (i.e., precipitated, complexed, adsorbed, or solubilized) of metals, sediment pH, and physical and chemical characteristics of the aquatic system (Morgan and Stumm 1991). Chemical partitioning can be defined as the identification and quantification of the different chemical species, forms, or phases present in sediment. Besides, heavy metals are associated with sediments in different ways, and their association determines mobility and availability (Ahumada et al. 1999). This type of association between metals and the sediments can be understood in detail by sequential extraction techniques. Heavy metals are distributed in sediments, as exchangeable bound, carbonate, iron–manganese oxide, organic matter, and residual fraction (Dean 2002).

A review of the earlier literature reveals that a good deal of attention has been paid to the heavy metal studies of sediment in various countries. A number of researches have been made in earlier publications on sediments contamination that caused by anthropogenic or natural activities (Aloupi and Angelidis 2001; Chiu-Wen et al. 2007; Evans et al. 2003; Liaghati et al. 2003; Karbassi and Shankar 2005; Santos et al. 2005; Matthieu et al. 2006; Jain et al. 2007).

The studies conducted in different locations in India have confirmed the serious contamination of river sediment by heavy metal (Sharma and Pandey 1998); Ganga River (Jain 2004), Yamuna River (Singh et al. 2005), Gomati river sediments (Jain et al. 2008), and Narmada river of Maharashtra state (Gholami and Srikantaswamy 2009) in Cauvery, India.

The Kabini River system in Mysore districts of Karnataka, India has a record of higher pollutants level

than normal values. In this concern, this study attempts to apply the enrichment factor and geochemistry index to understand the degree of contamination by heavy metals and its sources.

## Materials and methods

Riverbed sediments were collected from the surface along its main stream at 17 predetermined GPS recorded locations (Fig. 1). The sediments were stored in plastic vials and frozen at  $-20^{\circ}\text{C}$  pending analytical procedures. In the laboratory, sediment samples were defrosted at room temperature, dried at  $40^{\circ}\text{C}$  up to a constant weight, ground, and homogenized in mortar to a fine powder.

Total metals ( $\text{Cu}^{++}$ ,  $\text{Cr}^{+3}$ ,  $\text{Fe}^{+3}$ ,  $\text{Mn}^{++}$ ,  $\text{Ni}^{++}$ ,  $\text{Pb}^{++}$ , and  $\text{Zn}^{++}$ ) were determined by absorption atomic spectrophotometer technique after acid digestion. For digestion, 2 g of dried sample was put into a polytetrafluoroethylene vessel with 4 ml of  $\text{HNO}_3$ , 2 ml of  $\text{HCl}$ , and 2 ml of  $\text{HF}$ . For each digestion program, a blank was prepared with the same amount of acids.

The sequential extraction procedure is based on the methods of Tessier et al. (1979); 1 g sample was transferred to a Teflon vial for strong acid and high-temperature processing. Chemical partitioning studies were carried out in four sequential steps: (1) acetic acid 25 %v/v, (2) acetic acid 25 %v/v 0.1 M hydroxylamine hydrochloride, (3) 30 %  $\text{H}_2\text{O}_2$  “extraction with 1 M ammonium acetate”, and (4) hot 50 %  $\text{HCl}$  (Chester and Hughes 1967; Gibbs 1977).

In this study, to identify the association between heavy metals, chromium, copper, iron, lead, manganese, nickel, and zinc analyses, statistical tools such as cluster analysis, principal component analysis (PCA), and correlation matrix were exploited on raw data through using computer software package SPSS 13.

## Result and discussion

Concentration of copper, chromium, iron, manganese, lead, and zinc in bed sediments from sample station are presented in Table 1. The high value of chromium concentration at stations 5 and 6 seems due to textiles, paper mill, and leather industry in Nanajangud industrial area as well as domestic sewage. Since the pH was above 6, the chromium would probably be in the

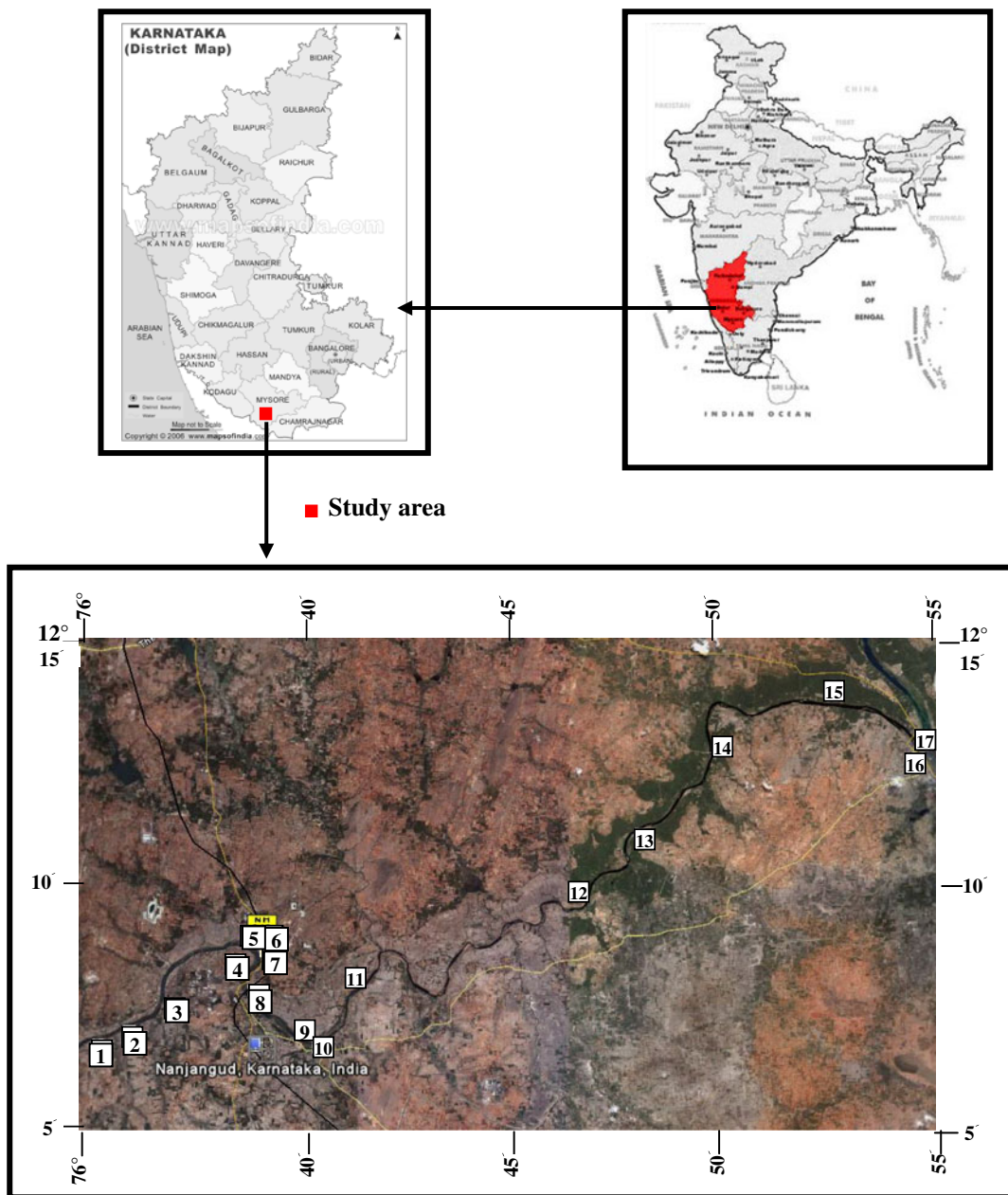


Fig. 1 Sample location map of the study area (Google image, 2009)

trivalent state and therefore be nontoxic. The high value of copper concentration at station 5 seems to be present at the pharmaceutical and electronic industry in Nanjangud industrial area; also at station 8, the industrial emission as well as Nanjangud municipal effluent that release to the Kabini River was attributed. The variation in copper at different station shows different sources of copper in the study area. The

geochemistry index has been identified as the degree of contamination by heavy metals from lithogenic and anthropogenic sources.

Iron distribution in nature is in oxidation states at  $Fe^{2+}$  and  $Fe^{3+}$ . The ferric oxides are very fine grained and carried by rivers either as stabilized colloids as adsorbed coatings on particles. In addition, much of the Fe content are fixed within the crystalline structure

**Table 1** Mean concentration of heavy metals in the Kabini riverbed sediments (milligram per gram)

No.	Sampling station name	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	Byalaru	236.5	105.66	1,668.37	547.33	65.33	5.46	80.36
2	Deburu	238.83	98.73	1,695.36	519	65.59	7.28	139.26
3	Kallahalli	198.71	84.26	1,477.66	523.6	46.86	5.45	43.9
4	Chikkayyana Chattra	273.5	61.1	1,326.42	535.66	34.28	11.5	64.03
5	Paper mill industry	437.97	154.43	1,775.83	535	278.13	25.38	188.66
6	Kattavadipura	402.62	66.66	1,356.66	427.43	107.53	9.2	68.16
7	Kempasiddanahundi	265.3	145.43	1,380.04	397.27	63.76	29.36	84.76
8	Bridge	236.83	159.03	1,769.61	389.42	42.62	29.50	53.7
9	Nanjangud Temple	280.43	129.33	1,598.69	301.66	99.83	5.08	80.16
10	Hejjige	267.86	116.04	1,637.18	299	42.79	12.99	43.83
11	Mulluru	134.06	126.73	1,362	364.32	259.06	5.74	154.5
12	Suttur	133.96	99.08	1,853.70	323.47	43.33	5.65	47.63
13	Thayur	142.43	104.53	1,838.35	331.97	76.46	4.56	152.26
14	Biligerihundi	210.13	95.83	1,480.87	379.56	57.13	5.45	39.36
15	Gargesvari	186.83	94.32	1,511.89	472.34	14.3	5.32	28.36
16	Hosa Thirumakudalu	227.9	57.66	1,461.54	470.66	11.5	5.32	46.76
17	Confluence Cauvery and Kabini	231.16	109.03	1,844.33	512	30.06	5.76	45.96
Min		133.96	57.66	1,326.42	299	11.5	4.56	28.36
Max		437.97	159.03	1,853.70	547.33	278.13	29.50	188.66
Mean		241.47	106.34	1,590.50	431.16	78.74	10.53	80.10
Standard deviation		81.94	30.11	185.29	89.07	76.02	8.73	48.37

of primary and secondary minerals and are totally nonreactive. A large portion may be soluble under reduced condition of typical anaerobic sediments, but essentially all of the potentially reactive Fe would be oxidized to sparingly soluble ferric oxyhydroxide under upland conditions (Gambrell et al. 1983). High concentration of iron in sediments could cause stress for bottom-dwelling organisms.

The high value of lead concentration at stations 5, 7, and 8 seems due to the presence of fuel combustion from industrial area and automobile emission of Nanjangud–Mysore road. Low hardness value in most stations of the Kabini River makes it more vulnerable to lead toxicity. Lead toxicity is a concern since the metal has a cumulative effect within an organism. Since low hardness values are evident in station 8, there is little dilution effect of the metal by Ca and Mg ions; therefore, more of the available lead can rapidly be taken by an organism. In this study, pH values were above 7, therefore the availability of Zn becomes very low and it precipitates.

The results of the PCA are presented in Tables 2 and 3. In the analysis, four principal components (PC) with eigenvalues higher than 1 were considered. PCA lead to a reduction of the initial dimension of the dataset to four components which explain 70.44 % of the data variation. Elements such as Zn and Ni were shown to be strongly associated in the first component, suggesting a natural geochemical association of major rock-forming elements in sediments; the rotated component matrix indicated that Cu and Pb were strongly associated in the second component (PC2). These elements may reflect anthropogenic contamination in the Kabini riverbed sediments. The third component included associated Cr and Mn which represented a natural input of these metals from parent rocks; iron was univocally isolated in the fourth component and has relatively weak association with all of the others. For understanding of the elemental mobility in the Kabini River, the chemical composition of surface sediments has to be determined.

Cluster analysis (CA) was applied on sediment samples in order to identify the degree of inter-element

**Table 2** Total variance explained and matrix of principal components analysis (significant loading factors are remarked in hold)

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
Total variance explained									
1	3.986	33.213	33.213	3.986	33.213	33.213	3.379	28.161	28.161
2	1.807	15.056	48.269	1.807	15.056	48.269	1.913	15.944	44.106
3	1.465	12.211	60.480	1.465	12.211	60.480	1.614	13.454	57.560
4	1.196	9.963	70.443	1.196	9.963	70.443	1.546	12.883	70.443

correlation. The clustering of elements indicates common anthropogenic sources. Heavy metal relationships were analyzed by correlation matrix (Table 4). The bed sediments result showed a significant positive correlation between Cu and Pb ( $r=0.620$ ) and it showed a positive correlation between Zn and Ni ( $r=0.793$ ). In general, correlation between metals agreed with the results obtained by CA. The influence of these interrelated elements was quantified by results of the PCA.

Cluster analysis showed that Cu, Pb, Zn, and Ni formed cluster “A” which shows that Cu content in sediments was not only due to its presence in the parent rocks but also due to anthropogenic effluents of industrial areas, and confirms the combination of metal affiliation of varied origin. Lead and copper demonstrated similar behavior as did Zn and Ni as a result from a variety of industrial activities. Cr formed cluster “B” and Mn showed cluster “C”, finally Fe forms cluster “D” and joins cluster B and C; meaning, the sources of Fe are different (Fig. 2).

**Table 3** Rotated component matrix of principal components analysis of Kabini River surface sediments (significant loading factors above 0.6 are remarked in bold)

Metal	PC1	PC2	PC3	PC4
Cu	0.275	0.660	-0.146	0.563
Zn	0.877	0.111	-0.111	0.165
Pb	0.050	0.889	0.130	0.128
Cr	0.331	0.461	0.553	-0.278
Ni	0.909	0.259	-0.090	0.017
Mn	0.183	-0.240	0.629	-0.007
Fe	0.048	-0.033	0.024	0.843

Rotation converged in five iterations

Chemical partitioning patterns for each metal and sampling point are shown in Table 5. The effects of heavy metals in the environment depend, to a large extent, on whether they occur in forms that can be taken up by plants or animals. A wide range of values for heavy metal concentrations was observed for the sediments in Fig. 3.

Percentile of elements in various sedimentary phases can be summarized as follows:

Exchangeable ion fractions: Pb (28 %)>Cr (22 %)>Cu, Mn (19 %)>Zn (18 %)>Ni (17 %)>Fe (15 %)

Carbonate fractions: Cu (21 %)>Pb (20 %)>Cr (19 %)>Mn (17 %)>Ni, Zn (14 %)>Fe (10 %)

Fe/Mn oxides fraction: Pb (18 %)>Cr (17 %)>Cu, Mn, Zn (13 %)>Ni (11 %)>Fe (3 %)

Organic matter fractions: Fe (24 %)>Mn, Cr, Cu (19 %)>Pb (11 %)>Zn(10 %)>Ni (8 %)

Residual fraction: Ni (50 %)>Fe (48 %)>Zn (45 %)>Mn (32 %)>Cu (25 %)>Cr, Pb (23 %)

Exchangeable species usually related to the adsorbed metals on the sediment surface. Lead and chromium in exchangeable forms can be easily remobilized into the Kabini River water and they are derived from natural and anthropogenic sources. High concentration in exchangeable fraction indicates high bio-availability of Pb.

The results from carbonate fractions reveal 21 % Cu and 20 % Pb. The study area receives inputs from urban and industrial effluents, particularly at stations 6 and 9. The significant concentration of Pb present in the bioavailable fraction is due to the influence of anthropogenic material. Relative concentration of Pb and Cr in Fe/Mn oxides fraction may be attributed to the flocculation of colloids on Pb and Cr in the Kabini River system. Relative concentration of Pb and Cr

**Table 4** Correlation matrix between metal bed sediment concentrations in the study area

		Cu	Zn	Pb	Cr	Ni	Mn	Fe
Cu	Pearson correlation	1						
	Sig. (two-tailed)							
Zn	Pearson correlation	0.412 <sup>a</sup>	1					
	Sig. (two-tailed)	0.000						
Pb	Pearson correlation	0.620 <sup>a</sup>	0.188	1				
	Sig. (two-tailed)	0.000	0.059					
Cr	Pearson correlation	0.161	0.225 <sup>b</sup>	0.452 <sup>a</sup>	1			
	Sig. (two-tailed)	0.106	0.023	0.000				
Ni	Pearson correlation	0.458 <sup>a</sup>	0.793 <sup>a</sup>	0.222 <sup>b</sup>	0.338 <sup>a</sup>	1		
	Sig. (two-tailed)	0.000	0.000	0.025	0.001			
Mn	Pearson correlation	-0.122	0.077	0.026	0.234 <sup>b</sup>	0.013	1	
	Sig. (two-tailed)	0.224	0.440	0.798	0.018	0.896		
Fe	Pearson correlation	0.402 <sup>a</sup>	0.198 <sup>b</sup>	0.065	-0.012	-0.018	0.017	1
	Sig. (two-tailed)	0.000	0.046	0.513	0.904	0.857	0.869	

<sup>a</sup> Correlation is significant at the 0.01 level (two-tailed)

<sup>b</sup> Correlation is significant at the 0.05 level (two-tailed)

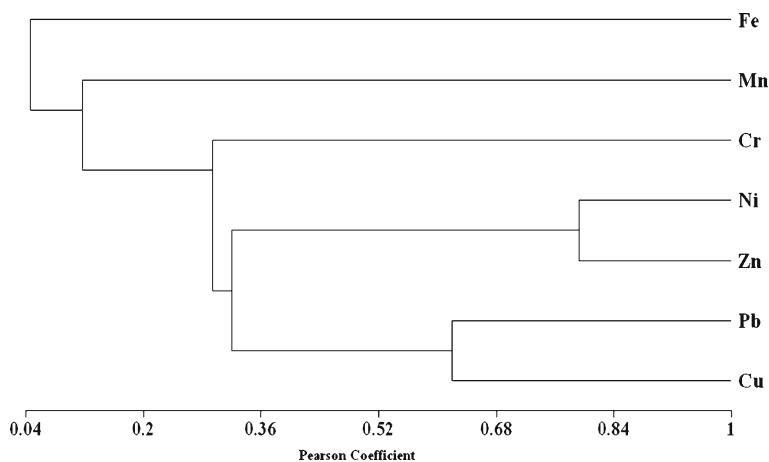
associated with this fraction are caused by the adsorption of these elements by the colloids of Mn and Fe (Jenne 1968). On the other hand, association with hydroxides of Fe and Mn acts to dissipate trace metals, especially Pb, due to large adsorption in surface areas. Significant associations between trace metals and Fe and Mn oxides in sediments have been recorded in regions that receive discharges of industrial effluents (Relic et al. 2005; Sakan et al. 2007).

Association of the metals with organic matter can be explained by the high affinity of the elements for the humic substances that comprise of these materials.

This is due to the formation of the stable metal complexes and insoluble metal sulfides that are important sinks for trace metals in sediments (Chandra Sekhar et al. 2004). Fe showed the highest content in the organic matter fraction.

These metals are strongly complexed in sediments and are released following degradation of the organic matter or oxidation of sulfides to sulfates. The observed behavior was probably due to the affinity of the metals for the organic matter present in water, given the high anthropogenic loadings in the study region (Alves et al. 2007).

**Fig. 2** Dendrogram of cluster analysis among metals in the Kabini riverbed sediment



**Table 5** Chemical analysis of heavy metals of the study area of Kabini riverbed sediments

Location	Ionexchangeable	Carbonates	Fe–Mn oxides	Organic matter	Residual
<b>Cu (ppm)</b>					
Kallahalli	18.5	23.21	18.1	5.225	37.825
Chikkayyana Chattra	13.0375	18.5	7.55	14.35	2.1625
Kempasiddanahundi	26.6	32.375	22.325	33.025	20.475
Nanjangud Temple	34.95	31.45	18.23	29.125	30.225
Mulluru	26	29.075	17.745	8.3	74.4
Thayur	20.075	22.03	14.05	26.4	31.75
Biligerihundi	11.67	16.805	5.335	28.425	8.225
Confluence Cauvery and Kabini	16.6	12.58	13.32	22.85	30.675
Mean	20.92	23.25	14.58	20.96	29.46
<b>Zn (ppm)</b>					
Kallahalli	13.8	12.56	4.2	2.7	20.925
Chikkayyana Chattra	28.95	3.725	3.35	9.425	12.15
Kempasiddanahundi	27.3	25.875	23.125	8.55	54.05
Nanjangud Temple	22.01	20.065	21	5.925	43.45
Mulluru	18.27	15.795	14.62	12.57	98.245
Thayur	16.57	14.55	14.65	15.425	96.35
Biligerihundi	3.1	1.575	4.74	11.775	12.5
Confluence Cauvery and Kabini	13.35	12.125	13.555	8.475	22.375
Mean	17.91	13.28	12.4	9.35	45
<b>Pb (ppm)</b>					
Kallahalli	2.34	1.14	0.8	Nd	4.31
Chikkayyana Chattra	3.4	1.7	1.6	0.375	4.525
Kempasiddanahundi	14.29	11.4	10.7	4.225	25.405
Nanjangud Temple	1.65	1	1	1	0.35
Mulluru	1.1	0.8	0.7	Nd	5.05
Thayur	1	0.6	0.05	0.85	2.15
Biligerihundi	1	0.23	0.16	Nd	2.8
Confluence Cauvery and Kabini	1.55	1.38	1.25	0.75	2.5
Mean	3.63	2.66	2.31	1.44	3.01
<b>Cr (ppm)</b>					
Kallahalli	48.726	35.726	33.251	35.426	47.001
Chikkayyana Chattra	63.71	51.86	45.31	43.87	68.87
Kempasiddanahundi	50.08	51.22	47.56	45.34	45.4
Nanjangud Temple	77.802	61.102	39.212	60.342	68.682
Mulluru	23.49	19.12	17.61	19.01	41.31
Thayur	25.15	21.66	19.27	25.88	36.5
Biligerihundi	30.28	27.58	34.58	35.99	26.39
Confluence Cauvery and Kabini	48	39.8	41.5	45.35	42.15
Mean	45.90	38.50	34.78	38.90	47.03
<b>Ni (ppm)</b>					
Kallahalli	16.78	12.98	8.69	4.3	31.55
Chikkayyana Chattra	14.36	10.84	6.76	6.735	17.595
Kempasiddanahundi	22.54	18.325	18.715	10.09	35.63

**Table 5** (continued)

Location	Ionexchangeable	Carbonates	Fe–Mn oxides	Organic matter	Residual
Nanjangud Temple	36.55	29.85	26.22	6.325	67.7
Mulluru	38.9	37.995	34.795	19.595	189.42
Thayur	16.175	13	12.13	9.225	49.71
Biligerihundi	9.425	12.35	8.225	5.6	37.5
Confluence Cauvery and Kabini	9.78	5.3	4	7.9	6.095
Mean	20.56	17.58	14.94	8.72	54.4
Mn (ppm)					
Kallahalli	102	95.525	58.1	62.35	165.025
Chikkayyana Chattra	90.15	100.5	60.225	70.2	179
Kempasiddanahundi	61.375	68.1	63.85	72.685	100
Nanjangud Temple	60.15	54.325	42.725	37.9	79
Mulluru	45.05	46.75	32.175	55.125	62
Thayur	64.95	34.725	32.375	83.65	96.6
Biligerihundi	74.75	56.025	46.925	50.3	88
Confluence Cauvery and Kabini	69.59	47.265	45.39	161.8	216
Mean	71	62.90	47.72	74.25	123.20
Fe(mg/g)					
Kallahalli	250.5	155.275	104.125	328.85	543.25
Chikkayyana Chattra	184.975	264.475	4.45	346.55	510.05
Kempasiddanahundi	93.725	56.9	34.4	360.2	741.775
Nanjangud Temple	252	160.675	85.1	283.75	781.975
Mulluru	188.525	129.85	48.55	347.2	574.875
Thayur	212.475	60.2	16.475	358.975	1,181.375
Biligerihundi	293.925	178.95	44.1	345.875	155.65
Confluence Cauvery and Kabini	216.6	86.475	24.45	363.25	1,004.225
Mean	211.59	136.6	45.20	341.83	686.64

It has been suggested that residual fraction is most important for uncontaminated sediments. In the present study, Cu, Cr, and Pb were associated with the lowest portion of residual fraction. In uncontaminated settings, the residual fraction is a significant geochemical phase for trace metal retention. Ni and Zn have 50 % and 45 %, respectively, in this fraction and attributes in less concentration in aquatic fauna and food chain than the other metals. The relative content of a metal in the residual phase can be used as a measure of the contribution of natural sources and also of the degree of contamination of the fluvial system, with a higher percentage indicative of lower levels of pollution (Singh et al. 2005).

With reference to the above study result, that bio-availability is related to solubility, metal bio-availability decrease in order of:

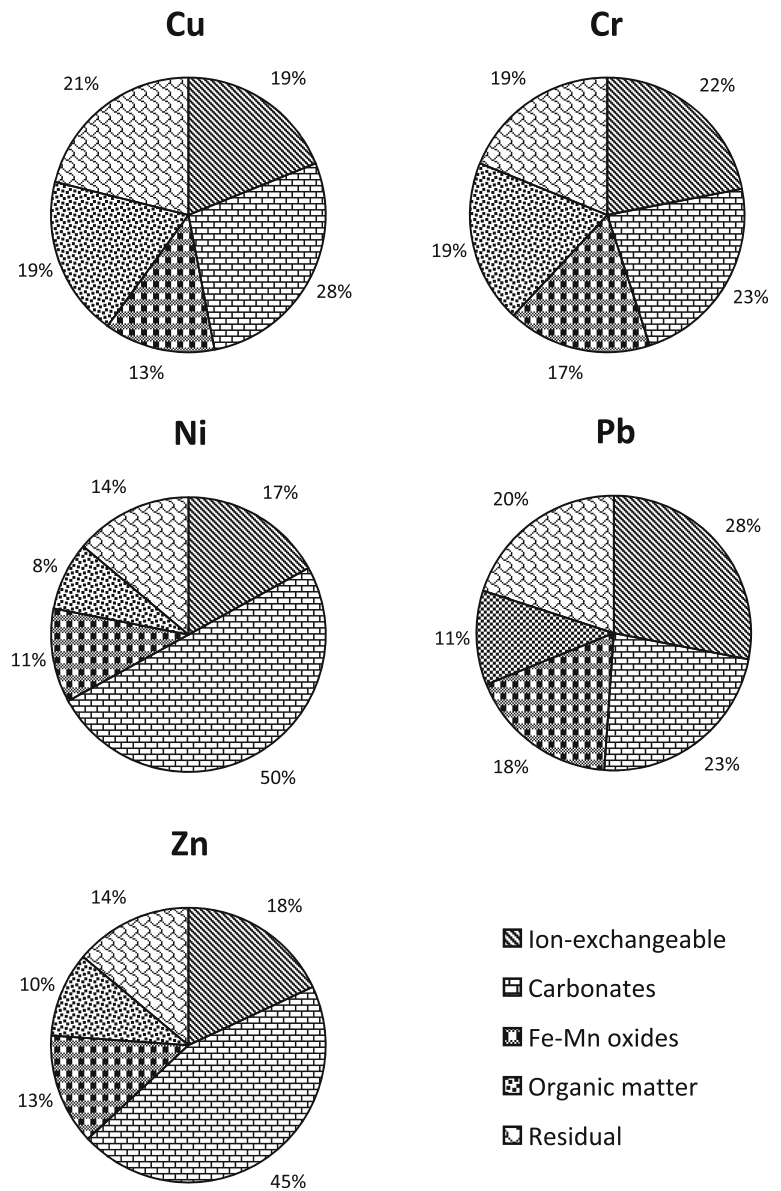
Exchangeable > sulfide ions > organic > residual (Ma and Rao 1997; Xiangdong et al. 2000).

Among the nonresidual fractions, the ion exchange fraction was much higher than other fractions in all stations. The percentage of lead, chromium, and copper in the nonresidual fractions was greater than the residual fraction. About 77 % of the lead and chromium in sediment was associated with the exchangeable, carbonate, organic matter, and oxidation fractions. These results indicate that lead and chromium have greater potential for mobilization from sediments to water because of their higher concentration at the ion exchangeable fraction.

The extent of sediment contamination was assessed using the enrichment factor (EF) and geo-accumulation index (I<sub>geo</sub>; Table 6). Enrichment factor is a geochemical approach to discriminate anthropogenic and natural



**Fig. 3** Percentage of chemical partitioning of trace metal in Kabini riverbed sediments



**Table 6** Comparison of various pollution indices in Kabini riverbed sediment

Heavy metal	EF	Igeo
Cr	52.44	1.14
Cu	63.52	1.23
Ni	9.40	0.27
Pb	2.79	–
Zn	9.56	0.36

sources and determine with confidence the degree of enrichment/contamination of given metals. It can be calculated as the ratio between the sample and the natural background

The mean EF values for Cr recorded at 52.44 while the highest EF value was found to be 102.52 at station 6. The mean EF values for Cu and Pb measured at 63.52 and 2.7, respectively, while the highest EF values were found to be 100.11 and 8.98 at station 7 which received a huge amount of effluents from Nanjangud industrial area and sewage discharges. Extremely high enrichment of Cu and Cr was recorded

in sediments from stations close to pulp and paper mills indicating a point source. The results also show that minor enrichment of Pb is from the effluents released due to industrial activities around the Kabini River.

The mean EF values for Ni and Zn was determined at 9.40 and 9.56, respectively, while the highest EF values are 36.13 and 21.55 at station 11. The results from these calculations show that Zn and Ni reveal significant enrichment in the sediment and that enrichment is due to the release of industrial wastewater to the river.

Table 6 shows the calculated values for the Kabini River sediments (Mueller 1979). Zn and Ni remain in class 1 (unpolluted), along the course of the Kabini River, suggest that there is no pollution with respect to Zn and Ni metals and Cu, Cr in class 2 attribute that the Kabini sediments are moderately polluted except in three stations (11, 12, and 13) which were unpolluted.

## Conclusions

The major sources of pollution of the Kabini River are the industrial effluents (return flows), agricultural runoff, and domestic and municipal sewage besides pedogenic background contributions. The source of heavy metals in the Kabini riverbed sediments is envisaged as additional inputs from anthropogenic sources over and above lithogenic sources. The heavy metal averages of riverbed sediments are above and more concentrated than the combined averages contributed by lithogenic sources.

The present study indicates that the heavy metals are in the least mobilizable fraction in the overlying water and in these sediments are to a great extent derived from multisource anthropogenic inputs besides geochemical background contributions. Assessment of sediment pollution by total heavy metal concentrations values, might not firmly guarantee the occurrence of deleterious ecological effects. Lead and chromium have higher potential for mobilization from the sediment because of their higher concentration at the exchangeable ion and sulfide ion bounded. Therefore, geoaccumulation index based on total concentration affirm the intensity of pollution.

A higher geoaccumulation index is to Cu and Cr concentration. Igeo value indicated that the sediment

at Kabini River was moderately polluted by Cu and Cr. This contamination can possibly enter into aquatic and solid food chain. It may, however, be added that higher metal values reflect to adsorbed metals in the deposited sediments due to turbulence generated by scavenging organisms at the sediment–water interface. The research result of the study reveal that to protect the river from further contamination, periodical monitoring of the level of pollution, control the mixing of effluent of the concentration of heavy metals in the region, environmental remediation, treatment of industrial effluent and municipal wastewater is warranted. It is essential to prevent direct input of agricultural runoff in minimizing metal remobilization impacts by improving the quality of water through sediment dredging.

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