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ORIGINAL ARTICLE

Assessment of heavy metal distribution pattern in the sediments of Tamirabarani river and estuary, east coast of Tamil Nadu, India

A. Chandrasekaran · M. V. Mukesh · S. Chidambaram · S. R. Singarasubramanian · S. Rajendran · R. Muthukumarasamy · M. Tamilselvi

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Abstract The present study aims to investigate the concentration and spatial distribution of trace metals in Tamirabarani river and estuary located in the southeast coast of India. Sediment samples collected from sixteen locations were analysed for Cu, Ni, Cr, Pb, Zn and Cd. The extent of pollution in these sediments was assessed using enrichment factor (EF), contamination factor (CF), geo-accumulation index (I_{geo}). The EF shows enrichment of Ni in the northern part of the estuary and that of Cu in the south and it is mainly due to the process of weathering. The contamination factor indicates Cd is more highly contaminated than other metals. I_{geo} index shows that Cd is moderately polluted and its spatial distributions clearly indicate that it is found in estuarine region. The comparison of metal concentration with other estuaries of India indicates that these metals are well below the permissible limit. The metals in the estuary of the study area indicate more of the predominance of natural process than other estuaries in India. It is evident that the samples of river and estuary area are dominantly due to the natural process rather than anthropogenic activity.

A. Chandrasekaran (✉) · M. V. Mukesh · S. Chidambaram · S. R. Singarasubramanian · R. Muthukumarasamy · M. Tamilselvi
Department of Earth Sciences, Annamalai University, Annamalainagar, Tamil Nadu, India
e-mail: geochandru@gmail.com

M. V. Mukesh
e-mail: mukeshearthsciences@gmail.com

S. Rajendran
Department of Earth Sciences, Sultan Qaboos University, Masqat, Sultanate of Oman

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Introduction

The occurrence of metal contamination in fluvial ecosystems is commonly due to urban and mining activities occurring in its watershed (Guasch et al. 2009; Ferreira da Silva et al. 2009; Sierra and Gomez 2010). Trace metals may produce toxic effects on aquatic organisms depending on metal speciation, which, in turn determines bioavailability, toxicity and metal accumulation in accordance with this environmental problem (Tessier and Turner 1995; Meylan et al. 2004).

Heavy metal pollution of an aquatic ecosystem has become a potential global problem; these heavy metals are among the most common environmental pollutants, and their occurrence in waters and sediments originated from natural or anthropogenic sources. A trace amount of heavy metals is always present in fresh waters from terrigenous sources such as weathering of rocks, which may be recycled through chemical and biological contaminates in sediments in these ecosystems (Muwanga 1997; Zvinowanda et al. 2009; Harikumar et al. 2009, 2010; Sekabira et al. 2010). Heavy metal contamination in sediments could affect the quality and bio-assimilation and bioaccumulation of metals in an aquatic ecosystem. Further, these metals are immobilised within the sediments and thus might be involved in absorption, co-precipitation and complex creation (Okafor and Opuene 2007; Mohiuddin et al. 2010; Sekabira et al. 2010). These elements accumulate in the sediments through heterogeneous physical and chemical adsorption mechanisms, depending upon the nature of the

sediment matrix and elements, Fe–Mn hydroxides (Awofolu et al. 2005; Mwiganga and Kanisiime 2005; Rabee et al. 2011).

The effect of heavy metals on soil depends upon the series of physical and chemical characteristics, such as texture, organic matter, pH, redox potential, etc., and the amount of trace metals in sediments is usually low. A part from clay and colloidal materials is also found to be active and contain organic matter, and they can act as a shield in controlling the reflux of trace metals in sediments from an estuary towards the coastal region (Harikumar et al. 2010). The absorption of heavy metal into sediments can be a good sign of man-induced pollution rather than natural enrichment of the sediment by weathering. Human activities transformed the geochemical cycle of trace metals, which bring environmental contamination (Nriagu and Pacyna 1988).

Heavy metals may enter into the ecosystems from anthropogenic sources, such as industrial wastewater discharges, sewage wastewater, fossil fuel combustion and atmospheric deposition (Linnik and Zubenko 2000; Campbell 2001; Lwanga et al. 2003; El Diwani and El Rafie 2008; Idrees 2009; Sekabira et al. 2010). The elements like Pb and Cd, etc. show signs of extreme toxicity even at trace level (Nicolau et al. 2006; Harikumar et al. 2010). The continuous accumulation of heavy metals into the environment can cause a serious problem to society. Therefore, heavy metal concentration in sediment unravels the history and intensity of local and regional pollution (Nyangababo et al. 2005; Sekabira et al. 2010).

Rivers are dominant pathways for metals transport (Miller et al. 2003) and trace elements may become significant pollutants of many small riverine systems (Dassenakis et al. 1998). The behaviour of metals in natural waters is a function of the substrate sediment composition, the suspended sediment composition and the water physico-chemical properties. During transport, the trace elements undergo numerous changes due to dissolution, precipitation, sorption and complexation phenomena, which affect their behaviour and bioavailability (Dassenakis et al. 1998; Abdel-Ghani et al. 2007; Akcay et al. 2003; Nicolau et al. 2006). Verslycke et al. (2003) studied that salinity affects dissolved metal speciation and toxicity in surface waters and they reported a decreasing toxicity to the estuarine waters upon increasing the salinity from 5 to 25 ‰ and attributed this to lower activities of the free trace metal ions. The present work aims to understand the behaviour of certain heavy metals like Cu, Pb, Cr, Zn, Fe, Ni, and Cd in the surface sediment of the Tamirabarani river and estuary.

Materials and methods

Study area

Tamirabarani river originates from western Ghat hills in the study area and confluences in the East coast of Bay of Bengal. The present estuarine region falls in the part of Tirunelveli and Thoothukudi districts, east coast of Tamil Nadu state, and is located between 8°25N and 9°10N latitudes and 77°10E and 78°15′E longitudes (Fig. 1). The study area is blessed with deltaic system with different active and inactive distributaries. The southwestern part is dominated by the river and the northern part by the sea. The tidal impact is also noted along the distributary channels (Magesh 2011).

Sediments sampling and analysis

In the study area, sixteen sediment samples were collected at the river mouth estuary and distributary channels (Fig. 2). Each sampling location was identified and recorded using a hand-held GPS (Magellan); surface sediment's samples collected were packed in thick polyethylene bags. In the laboratory, the collected samples were frozen at −4 °C to avoid soil contamination. The freezing of the samples below −4 °C, prevents the growth of microbes or bacteria, which can result in the variation of metal in sediments. These samples were then dried in a hot-air oven at 40 °C and after homogenization using pestle and mortar; later they were sieved to less than 2 mm and stored in polyethylene bags for further analysis (Praveena et al. 1997; Shetye et al. 2009). The sediment's samples were digested and extracted based on the procedure of Manasrah et al. (2010) subjected for the assessment of trace metals using AAS with specific flame and wavelength (Atomic Absorption Spectrometer, (Elico make)) using a series of solution over the range 2–10 mg/l. The concentration of the metals was normalised and inferred for the following parameter.

Determination of enrichment factor (EF)

Enrichment factor (EF) is the proportional abundance of the chemical elements that helps to assess the degree of contamination and to understand the distribution among the elements of anthropogenic origin from sites by individual elements in sediments. EF computed relative to the abundance of species in source material to that found in the Earth's crust is considered as a better method for understanding the geochemical trends (Simex and Helz 1981; Praveena et al. 2007; Harikumar and Jisha 2010; Sekabira et al. 2010).

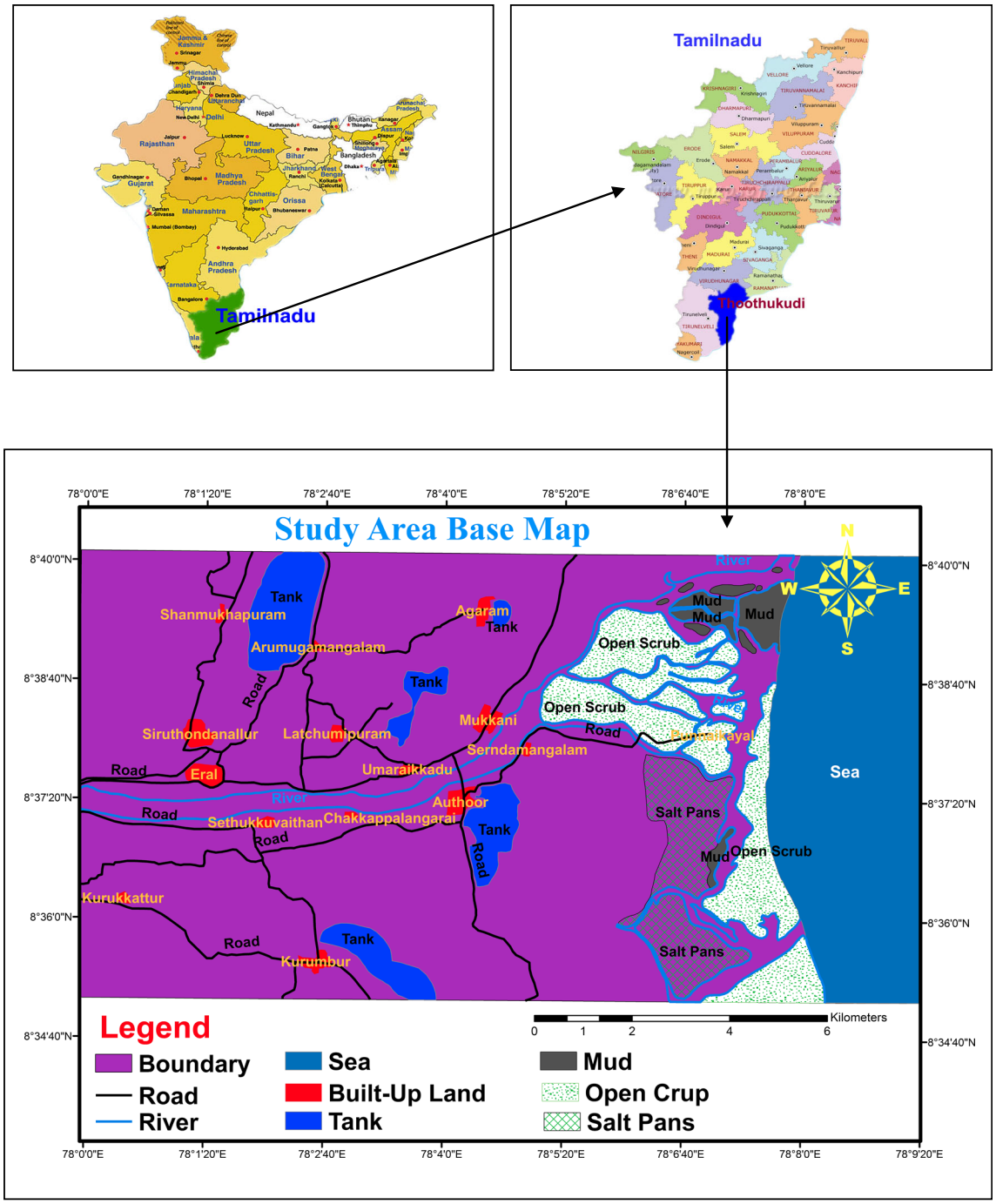

Fig. 1 Study area base map

An element qualifies as a reference, if it is of low occurrence variability and is present throughout the environment in trace amounts (Loska et al. 2003; Sekabira et al. 2010). Different enrichment calculation methods and reference material have been reported by many researchers like Ogusola et al. (1994), Gaiero et al. (1997), and Sutherland (2000). Deely and Fergusson (1994) proposed Fe as an acceptable normalisation element to be used in the calculation of the EF, as they considered the Fe distribution was not related to other heavy metals. Fe usually has a high natural concentration; therefore, it is not substantially enriched from anthropogenic sources in estuarine sediments (Niencheski et al. 1994) (Table 1).

EF = (Cn/Fe) sample/(Cn/Fe) background, where, Cn is the concentration of element "*n*". The continental crustal value of Fe was considered as background value (Turekian and Wedepohl 1961).

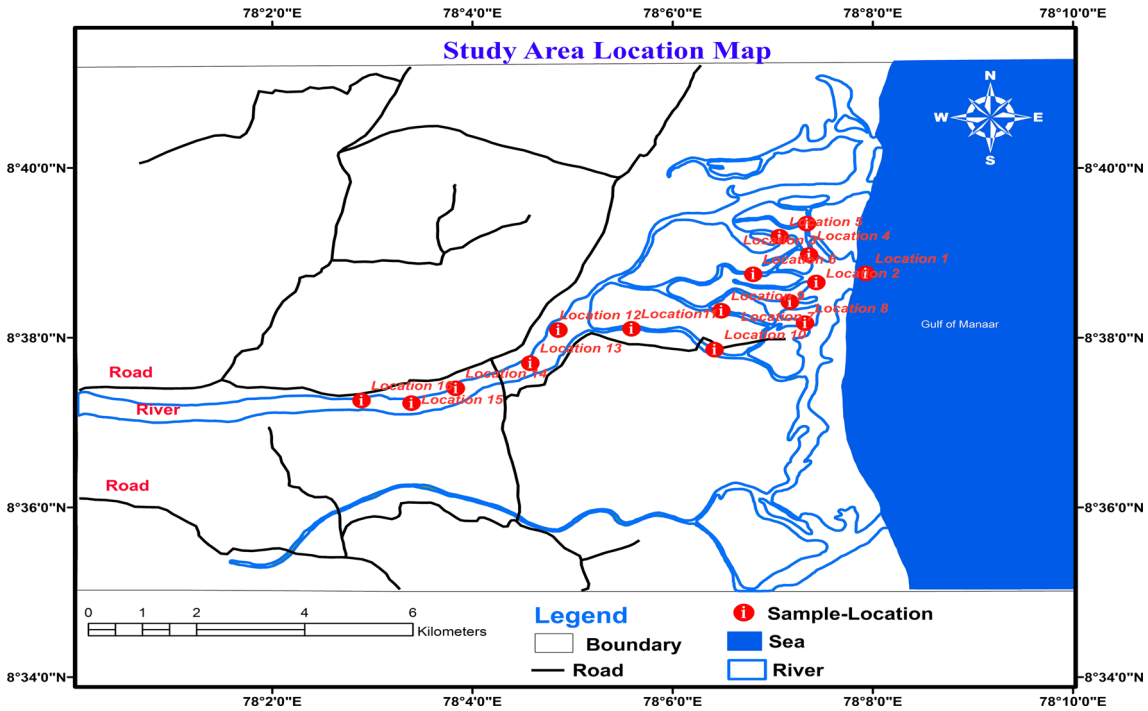

Fig. 2 Study area location map

Determination of contamination factor

The levels of contamination of sediment by metals are frequently expressed in terms of a contamination factor (CF). Hakanson (1980) has suggested a CF and degree of contamination. Here CF is calculated as follows:

$$\mathrm{CF} = \frac{\text{Metal content in the sediment}}{\text{Background level of metal}}$$

Crustal average values of specific metals were considered as background values (Turekian and Wedepohl 1961; Taylor and McLennan 1981). If $\mathrm{CF} < 1$ refers to low contamination; $1 \geq \mathrm{CF} \geq 3$ means moderate contamination; $3 \geq \mathrm{CF} \geq 6$ indicates considerable contamination and $\mathrm{CF} > 6$ indicates very high contamination (Table 2).

Geo-accumulation index (I_{geo})

Enrichment of metal absorption was calculated by adopting Muller (1969) methods, termed the geo-accumulation index (I_{geo}). This method concludes the metal pollution in terms of seven (0 to 6) enrichment classes ranging from background concentration to very heavily polluted. It is calculated as follows:

$$I_{geo} = \log_2(\mathrm{Cn}/1.5 \times \mathrm{Bn})$$

where Cn = measured concentration of heavy metal in the Tamirabarani sediment. Bn = geochemical background value of average crustal value (Turekian and Wedepohl 1961) of the specific element (n). The factor 1.5 is used for the possible variations of the background data due to lithological variations. Seven different classes for geo-accumulation index provided by Muller (1969, 1981) have been used in the present study (Table 3).

In this I_{geo} classification, 0 suggests the lack of contamination, while the I_{geo} class 6 highlights upper limit of contaminations. Higher contamination shows the extreme enrichment of the metals relative to their background values (Harikumar et al. 2010; Sekabira et al. 2010; Riyadi et al. 2012).

Result and discussion

The total trace metal concentrations for each sampling site found in sediments of Tamirabarani river and estuary are depicted in Table 4. The metal content ranges as follows: Pb 12.930–4.480 ppm; Cd 4.920–1.410 ppm; Cr 145.500–58.300 ppm; Cu 17.820–2.200 ppm; Zn 39.740–9.300 ppm; Ni 15.200–7.830 ppm. The mean concentrations of these metals are 7.301, 2.610, 97.162, 7.758, 27.534, and 11.852 ppm for Cd, Cr, Cu, Zn and Ni, respectively. The ascending order of average concentration of metals is as follows: Cd < Pb < Cu < Ni < Zn < Cr. These are calculated from the enrichment factors of the elements in the sediment's samples of Tamirabarani river.

The difference in concentration is mainly attributed to the difference in the magnitude of input for each metal in the sediments or the difference in the removal rate of each metal from the sediment (Ghrefat and Yusuf 2006). The results specify that the Cd levels found in the sediments of study area are hazardous to the aquatic system and public health.

Sharma et al. (1999) used both Al and Fe to distinguish natural and anthropogenic sources in recent sediments from Texas estuaries. Abrahim and Parker (2008) have also used Fe as a normalising base in EF calculation to assess the contamination of marine sediments. Naturally, derived elements have an EF value of near identity, while elements of anthropogenic origin have EF values of several orders of magnitude (Kamau 2002; Valdes et al. 2005; Ghrefat and Yusuf 2006; Abrahim and Parker 2008; Akoto et al. 2008; Dragovic et al. 2008). Hence, Fe is used as the normalising base for the metals in sediments of the present study.

Based on Zhang and Liu's (2002) categorization, if EF values between 0.5 and 1.5 indicate that these metals are entirely derived from crystalline materials or natural processes, while EF values greater than 1.5 suggest that the sources of these metals are of enriched relative to average continental crust, it could be of anthropogenic origin. All the heavy metals irrespective of locations have EF less than 1.5; they are comparable to continental crust, which indicates their source might be only from the natural weathering of exposed rocks at the river and the estuary without any additional input.

Few authors (Sekabira et al. 2010; Harikumar and Jisha 2010; Sutherland 2000) derived six categories as background concentration <1, depletion to minimal enrichment 1–2, moderate enrichment 2–5, significant enrichment 5–20, very high enrichment and 20–40 extremely high enrichment >40 (refer Table 1). It was found that all the samples fall below 1 and thus it is inferred that they represent the background concentration (Charkravarty and Patgiri 2009; Olubunmi and Olorunsola 2010; Mmolawa et al. 2011).

The spatial representation of the EF (Fig. 3) for analysed elements shows that comparatively higher enrichments of Ni and Cu are noted in the samples. It is also interesting to note that the EF of Ni is higher in the northern part of the estuary (10, 5 and 1) and that of Cu in the southern part and along the river course (12, 15, 14 and 16). Moreover, the samples with higher Ni concentration are found near the sea interface, which has high pH and salinity (Chidambaram et al. 2010); this also infers the fact that they are enriched in the finer size fractions than those samples in the southern part of the study area (Hema et al. 2002). Gambrell et al. (1991) also studied salinity effects during the oxidation of reduced metal-polluted brackish marshy sediments and Ni mobility. According to Millward and Liu (2003), the extent of metal desorption from sediments which were suspended in seawater followed the general order Ni > Cu, which is later adsorbed to surficial/bed sediments. Lores and Pennock (1998) concluded that salinity affects the binding of metals.

Statistical analysis is also used to understand the geochemical association between metals and to infer the hidden process (El-Hasan et al. 2006). The initial step in multivariate analysis is computation of correlation matrix,

Table 1 Enrichment factor (EF)

Range	Enrichment factor (EF)	Location					
		Cu	Ni	Cr	Pb	Zn	Cd
<1	Background concentration	1–16	1–16	1–16	1–16	1–16	1–16
1–2	Depletion to minimal enrichment,	–	–	–	–	–	–
2–5	Moderate enrichment	–	–	–	–	–	–
5–20	Significant enrichment	–	–	–	–	–	–
20–40	Very high enrichment	–	–	–	–	–	–
>40	Extremely high enrichment	–	–	–	–	–	–

Table 2 Contamination factor (CF)

Range	Contamination factor (CF)	Location					
		Cu	Ni	Cr	Pb	Zn	Cd
<1	Low contamination	1–16	1–16	1, 2, 3, 4, 5, 7, 8, 12, 13, 14, 15, 17	1, 3–16	1–16	
1–3	Moderate contamination	–	–	6, 9, 10, 11	2	–	–
3–6	considerable contamination	–	–	–	–	–	–
>6	Very high contamination	–	–	–	–	–	1–16

Table 3 Geo-accumulation index (I_{geo})

Class	Geo-accumulation index (I_{geo})	Location					
		Cu	Ni	Cr	Pb	Zn	Cd
<0	Unpolluted	1–16	1–16	1–16	1–16	1–16	–
0–1	Unpolluted to moderately polluted	–	–	–	–	–	–
1–2	Moderately polluted	–	–	–	–	–	–
2–3	Moderately polluted to highly polluted	–	–	–	–	–	3, 5, 8, 9, 10, 14, 15
3–4	Highly polluted	–	–	–	–	–	1, 2, 4, 6, 7, 11, 12, 13
4–5	Highly polluted to very highly polluted	–	–	–	–	–	–
5–6	Very highly polluted	–	–	–	–	–	–

Table 4 Heavy metal concentration of sediments samples in (ppm)

S.no.	Cu	Ni	Cr	Pb	Zn	Cd
1	2.2	ND	58.6	10.43	18.6	4.21
2	3.92	7.83	ND	12.93	9.3	4.92
3	3.74	ND	94.5	ND	ND	1.42
4	5.44	ND	ND	5.26	20.27	2.81
5	15.85	ND	ND	ND	29.17	1.45
6	13.86	15.2	112.3	ND	24.1	4.22
7	9.78	11.8	ND	ND	12.66	2.88
8	2.18	ND	58.3	ND	74	1.41
9	15.84	ND	120.4	3.48	30	2.11
10	7.92	ND	103.3	ND	16.07	1.46
11	ND	11.93	145.5	5.36	39.74	2.88
12	17.82	12.5	ND	8.57	30.86	2.78
13	10.85	ND	ND	ND	16.1	2.9
14	10.78	ND	ND	ND	47.77	2.22
15	ND	ND	84.4	6.96	26.63	1.48
16	3.96	ND	ND	5.42	17.75	ND
Mean	7.758	11.852	97.162	7.301	27.534	2.61
Max	17.82	15.2	145.5	12.93	39.74	4.92
Min	2.2	7.83	58.3	3.48	9.3	1.41

which gives interrelationship among the set of variables. After determining correlation matrix, correlation coefficient is measured of interrelationship for all pairs of constituents (Ashley and Lloyd 1978). The correlation coefficient expresses numerically the extent to which two variables are statistically associated. Correlation coefficients <0.5 are supposed to exhibit poor correlation. Correlation coefficient of 0.5 is termed as good correlation and >0.5 is termed to have excellent correlation. The correlation analysis of the metal concentration in sediments reveals that good correlation exists between Cu, Ni and Cr. Furthermore, between Pb and Cd, Pb and Cd have negative correlations with Cu, Ni and Cr, indicating a different source. Fe shows poor negative to poor positive correlation with other metals. This implies that metal concentration in sediments depends on release processes which are multiphasic, with the first set of processes possibly controlling early release and different sets controlling longer-term release (Forstner and Wittmann 1989; Caetano et al. 2003; Eggleton and Thomas 2004). For example, in the estuarine region of the study area bioturbation, microbial processes, and sediment oxidation can lead to significant fluctuations in metal content by changing their binding form (Simpson et al. 1998; Saulnier and Mucci 2000; Zoumis et al. 2001).

Further, it is obvious that the concentrations of Cr and Ni provide information on the provenance and shows enrichment when derived from a mafic source (Wronkiewicz and Condii 1989). Higher values of Cr and Ni, are also attributed to intense chemical weathering of the source rocks especially in tropical environments (Negender Nath et al. 2000). The correlation effect was strongest for Cd and Pb and attributed to their complexation with chloride ions. Hence, the adsorbed Ni, Cu, and Zn in sediments show that it is mainly governed by salinity of the water.

The comprehensive analysis of the contamination factor for the average values of the metals in the study is compared with the background and toxicological reference values of sediments. It appears that all the metals are low to moderately contaminated, except for Cd, which shows very high contamination. It is apparent that the average total concentration of Cadmium concentration in the sediment samples exceeded the geochemical background (average shale). It is mainly due to the fact that Cadmium uptake from water decreases with increasing salinity up to 10 ‰ (Du Laing et al. 2009).

This clearly illustrates that ascending salinity promotes Cd desorption from sediments, hence increases total Cd concentrations in the water column and Cd uptake by organisms. It is also substantiated by studies of Du Laing et al. (2002) that increasing Cd concentrations in ground-dwelling spiders, living on estuarine marshes with increasing salinities, indicates the prevelence of Cd in higher saline environments and the uptake by these organisms. It may also be understood that this less bioavailable Cd chloride complex may be adsorbed on the

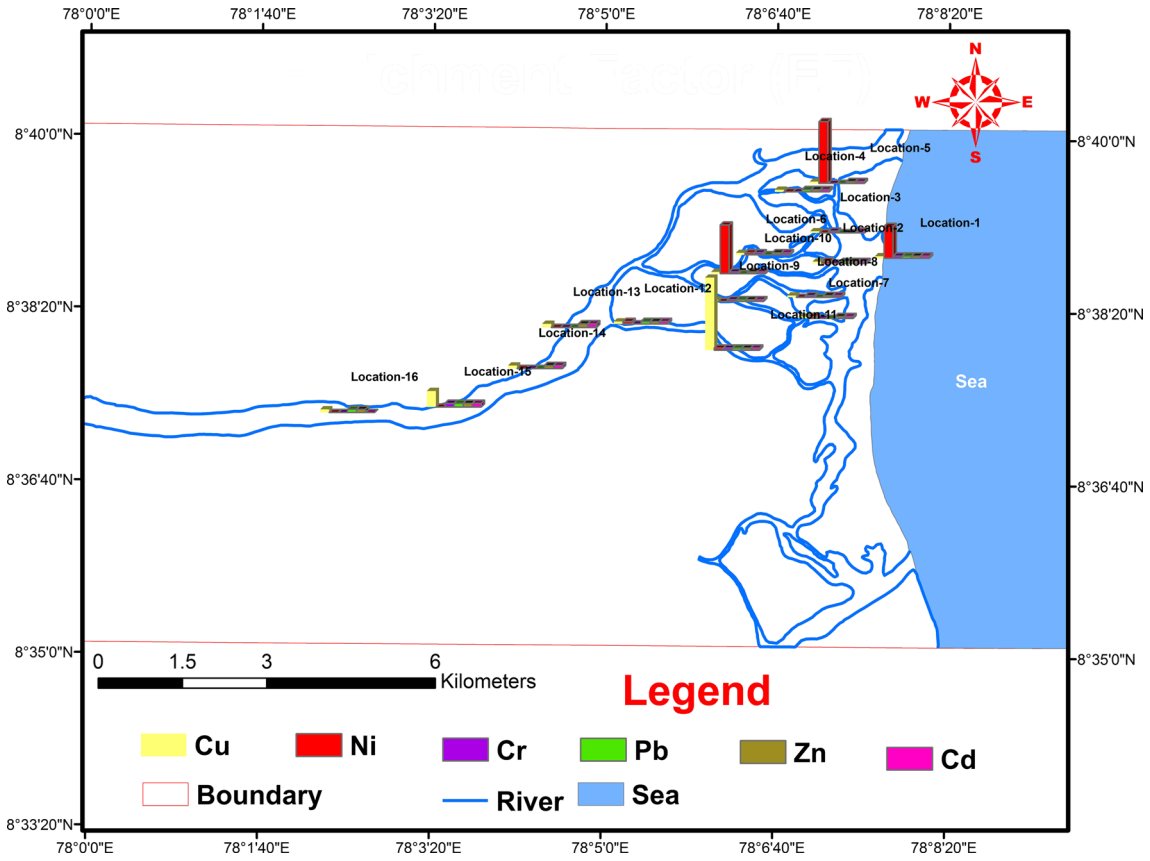

Fig. 3 Enrichment factor (EF) of Tamirabarani sediments

surficial sediment of estuarine. This further states that higher Cd bioavailability and toxicity with decreasing salinity is previously observed for living organisms in close contact with the water column, such as mussels (Fischer 1986; Stronkhorst 1993) and invertebrates (McLusky et al. 1986). The elemental contribution and enrichment of metals compared with the toxicological levels shows that Tamirabarani river and estuary sediments are moderately polluted. The spatial distribution (Fig. 4) of the contamination factor shows higher values for Cd are nearer the estuary region with varied salinity due to the tidal fluctuation, which is in agreement with the earlier interpretations.

The I_{geo} method was used to calculate the metal contamination levels of the samples collected in the study area. The average I_{geo} class <0 indicates unpolluted nature, but for that of Cd it shows moderately polluted to highly polluted levels. Details of the I_{geo} values for individual elements in the 16 locations are presented in Table 3. The negative I_{geo} values found in the table are the results of relatively low levels of contamination for all metals except Cd. This factor is not readily comparable to the other indices of metal enrichment due to the nature of the I_{geo} calculation, which involves a log function. Based on the classification system proposed for I_{geo} factors, all samples have moderately polluted to highly polluted index for Cd. This higher value is mainly due to the salinity factor as discussed earlier. The I_{geo} "uncontaminated" designation is clearly inappropriate as part of an overall description of the heavy metal results for sediments from this estuary. Spatial representation of I_{geo} (Fig. 5) shows that higher values of Cd are noted in the estuarine part of the study area and it decreases inland.

Earlier studies on this estuary by Magesh (2011) inferred that Cd concentration is due to pollution. The present study infers that it is due to natural source, similar to the present results that Lee et al. (2008) found that heavy metals concentration in the sediment varied with physico-chemical factors of seawater (i.e. dissolved oxygen, temperature and pH). Moreover, production of organic carbon in seawater due to phytoplankton growth and chelation of dissolved metals followed by their settlement increases the heavy metal concentration in the sediment (Lee et al. 2008). Hence, it is inferred that the variation of this metal is mainly due to the variation in physico-chemical factors in the estuary and not due to pollution.

Still, the velocity and duration of freshwater flow control the arrival of rainfall-entrained sediment to exposed

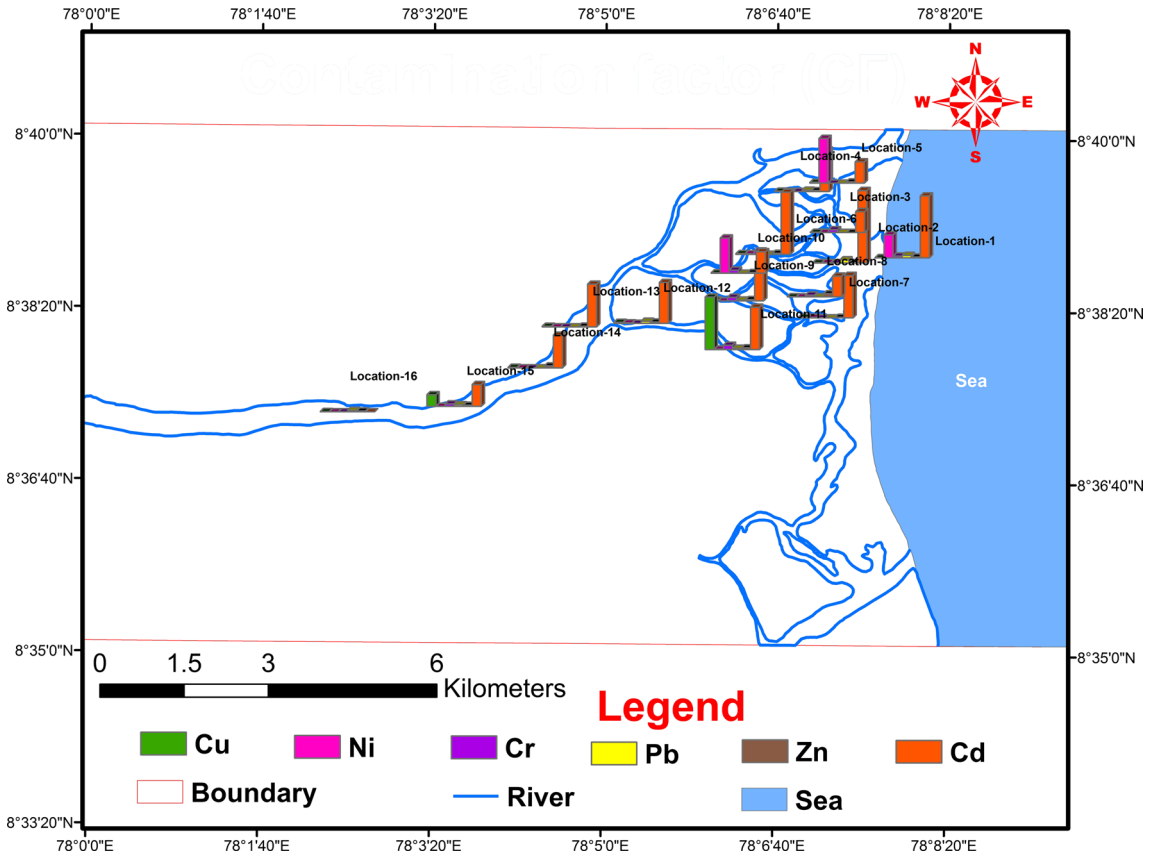

Fig. 4 Contamination factor (CF) of Tamirabarani sediments

intertidal creeks, and the focused flow is routed to the larger sub-tidal channels. In the sub-tidal zone, wider redistribution or export to the coastal ocean may occur with tidal circulation (Torres et al. 2004). Hence, the degree to which the intertidal creeks dissect the landscape reflects the sediment redistribution. In such a scenario, it is also inferred that the coarser sediments are more concentrated with Cu near the river mouth and the finer sediments are distributed along the estuary, which might have higher concentrations of Ni. Geomorphologically, it is witnessed that the coarser sediments are near the river mouth and the finer sediments are concentrated in the estuary as observed in the nearby Pichavaram Mangroves (Ramanathan et al. 1999). Hence, correlating the distribution of Cu and Ni shows that Cu is more concentrated near the river mouth, where the sediments are inferred to be coarser; and the Ni is concentrated in the fine-grained estuarine region. This relation is also well established in the correlation which indicates that Cu–Ni have good correlation indicating the same source but the distribution may be varying with respect to size of the particle. The fine-grained particles are found in the northern part of the study area near the river–ocean interface in northern part of estuary.

The comparison of the metal concentration with the other estuaries of India (Table 5) shows that they are well below the permissible limit and it is interesting to note that the estuary shows the predominance of natural process than other estuaries in India and toxicological reference of the world. Further, the study shows that Cd concentration is higher than the Crustal values (Table 6). The results specify that the Cd levels found in the sediments of the study area are hazardous to the aquatic system and public health.

Conclusion

A quantitative geochemical analysis of the sediments in Tamirabarani river and estuary sediments reveals dominance of metal concentration is as follows: Cu > Pb > Zn > Ni > Cr > Cd. The concentration of trace metals in the sediments is chiefly due to the influence of natural

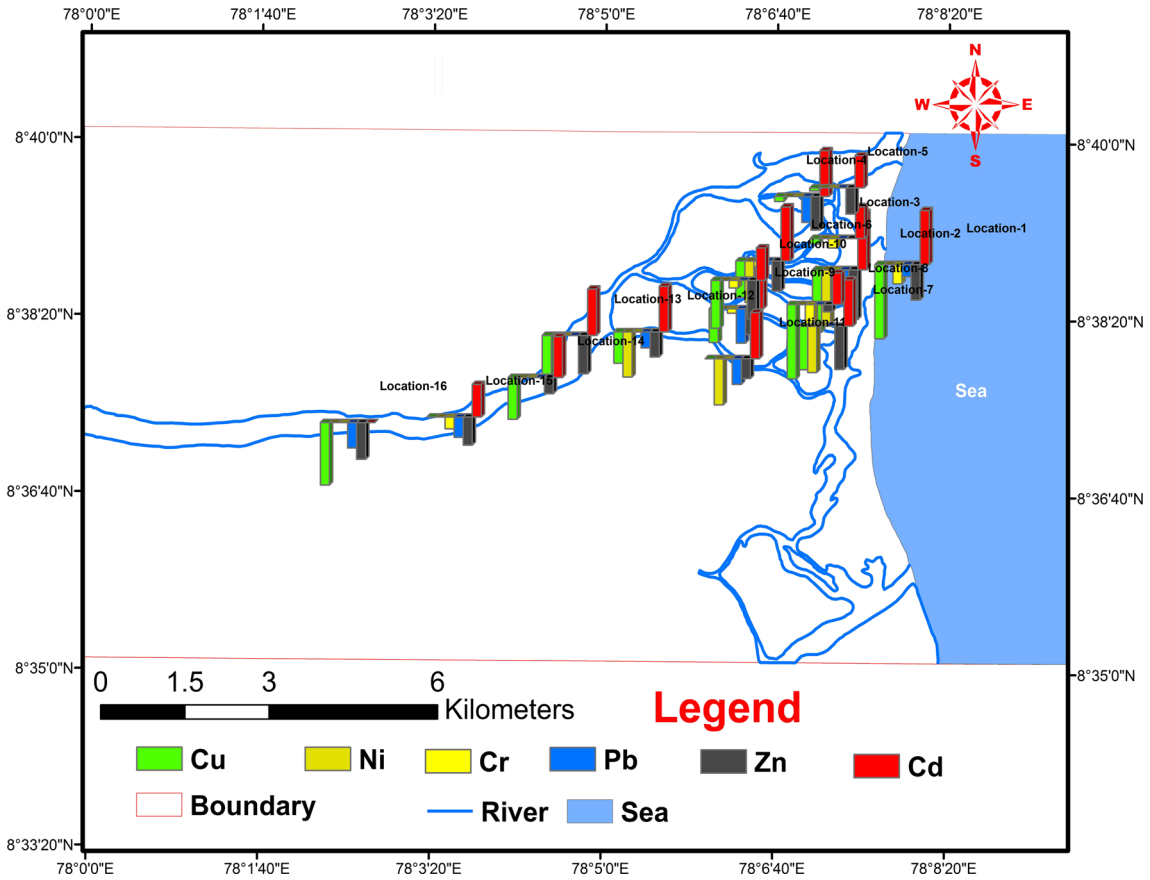

Fig. 5 Geo-accumulation index (I_{geo}) of Tamirabarani sediments

Table 5 Comparison of the metal level in the estuary sediments from different area of India

Location	Fe	Mn	Cu	Cr	Co	Cd	Ni	Pb	Zn
Pichavaram (μg g^{-1}) (Ramanathan et al. 1999)	32,482	701	32	141.2	NA	6.96	62	11.2	89
Pondicherry (μg g^{-1}) (Govindasamy and Kannan 1991)	NA	NA	34.59	NA	28.93	7.31	33.51	NA	104.6
East coast estuarine (μg g^{-1}) (Hema et al. 2002)	28,000	777	NA	318	12	NA	582	11	125
Vellar estuary (μg g^{-1}) (Ananthan et al. 1992)	1,511	2,156.5	36.5	NA	NA	NA	NA	NA	133.5
Cauvery estuary (μg g^{-1}) (Biksham and Subramanian 1988)	1.76 %	319	12	NA	64	NA	NA	10	26
Present study average (ppm)	13.764	NA	7.758	97.162	NA	2.61	11.852	7.301	27.534

process. The spatial distribution of EF of different elements displays that Ni is higher in the northern part of the estuary and Cu in southern part along the river course. The contamination factor shows Cd with very high contamination and Cu, Ni, Cr, Pb, Zn are less contaminated. The study also adheres to the fact that the salinity and other physio-chemical parameters of waters affect the binding property of metals. The contamination factor shows higher values for Cd near the estuary region and inferred as influenced by salinity. The Cd values in the estuary region are higher due to variation in salinity, which governs the formation of non-bio available Cd chloride complex. The higher Cd value in EF is found throughout the estuary sediment, and the I_{geo} value reflects highly polluted nature and other elements are unpolluted. The study reflects the fact that the salinity and sediment size governs the EF. Further, the CF

Table 6 Concentration of trace metals in sediment samples of Tamirabarani river and estuary with geochemical background and toxicological, reference values for river sediments (mg/g)

	Geochemical back ground		US DOE			Canadian EQG		US EPA	Ontario MOE	Japan's		Present study average (ppm)
Trace metal	Shale standard	Continental crust	TEC	PEC	HNEC	ISQG	PEL	TRV	LEL	SEL	EQS	
Cu	45	55	28	77.7	54.8	35.7	197	16	16	110	125	7.758
Ni	68	76	39.6	39.6	37.9	–	–	–	–	–	–	11.852
Cd	0.3	0.2	0.59	11.7	41.1	0.6	3.5	0.6	0.6	10	1	2.61
Pb	20	12.5	34.2	396	68.7	35	91.3	31	31	250	0.01	7.301
Zn	95	70	159	1532	541	123	315	110	120	820	–	27.534
Cr	90	100	56	159	312	37.3	90	26	26	110	_	97.162

Turekian and Wedepohl (1961), Taylor (1964), Jones et al. (1997), Environment Canada (2002), US EPA (1999), OMOE (Ontario Ministry of Environment) (1993) and MOE-Japan (2004), Gamo (2007)

TEC threshold effect concentrations, *PEC* probable effect concentrations, *HNEC* high no effect concentrations, *ISQG* interim sediment quality guideline, *PEL* probable effect level, *TRV* toxicity reference values, *Ontario MOE* Ontario Ministry of Environment, *LEL* lowest effect levels, *SEL* severe effect level, *Japan EQS* Japan's Environmental Quality Standard, *Canadian EQG* Canadian Environmental Quality Guidelines, *USEPA* US Environmental Protection Agency

and I_{geo} of sediments are governed by the physico-chemical parameters in the water, sediment interface.

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