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Depositional environment and elemental distribution with time in mudflats of dharamtar creek, west coast of India

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Two sediment cores collected from intertidal mudflats of Dharamtar creek, one near the mouth and the other from the middle region of Amba River were analyzed for sediment components, organic carbon and selected metals (Al, Fe, Mn, Ni, Co, Cr, Zn and Pb). The sediments are mainly composed of silt and clay contributing greater than 90% in both the cores, indicating calm environment prevailed during deposition of sediments. However, between the two cores, sediments in the middle estuarine region were deposited in relatively violent hydrodynamic environment compared to that near the mouth of the creek. Organic carbon concentration was found to be slightly higher near the mouth. The distribution of metals is largely controlled by sediment components, organic carbon and Fe-Mn oxyhydroxides at both the locations. When the average values are considered, Mn and Co shows higher concentration in the middle estuarine region whereas, Fe along with Al shows higher concentrations near the mouth. Enrichment factor calculated indicates minor enrichment of Mn, Fe and Zn and moderately to moderately severe enrichment with respect to Ni, Co, Cr and Pb in the creek. Index of geo-accumulation (Igeo) computed indicated that Dharamtar creek is moderately polluted with respect to Pb and Co, unpolluted to moderately polluted with Ni, Cr and Fe and practically unpolluted with Zn and Mn.

[**Keywords:** Depositional environment, Metal distribution, Geoaccumulation index, Dharamtar creek]

Introduction

Sediments are important carriers of metals in aquatic environment[1]. Sediments within estuarine regions are composed of different sedimentological and geochemical phase that acts as binding sites for metals entering the estuarine environment[2]. Metals are released into the aquatic environment by two main sources viz natural and anthropogenic. Natural sources mainly results from erosion of ore bearing rocks, windblown dust and volcanic activities, whereas anthropogenic sources include discharge of agricultural, municipal or industrial waste[3]. Some metals like Fe, Zn, Mn, Co are essential to living organisms but becomes highly toxic at higher concentrations whereas others such as Pb, Ni, Cr which are generally not required for metabolic activity and are toxic to living organisms even at quite low concentrations[4-5]. Metals have great ecological significance because of their toxicity, persistence and bioaccumulation capacity[6-7] and as heavy metals cannot be biologically or chemically degraded and tends to accumulate into the food-chain, pose serious threat to the environment[8].

Over the last few decades, the study of sediment cores has shown to be an excellent tool for establishing the effects of anthropogenic and natural processes on depositional environments[9-11]. Present study consists the first information regarding concentration, distribution and possible sources of elements (Al, Fe, Mn, Zn, Cr, Co, Ni, Pb) in core sediments of Dharamtar creek, west coast of India.

Materials and Methods

Study Area

Dharamtar creek is the confluence of Karanza creek, Patalganga river and Amba river, opening into southern part of Mumbai harbour (Fig. 1). The Dharamtar creek is 9-10 m deep near its mouth[12]. Amba River forms a major estuarine system of Dharamtar creek[13] and originates from the mountain range of Sahyadri, follows a narrow and meandering course of over 140 km before opening finally into Dharamtar creek. Amba estuary is shallow with average depth of 3 m during an average tide[14] but 2.6 km wide near its mouth during spring tide[15]. The tides here are semidiurnal and currents are entirely governed by tides during non-monsoon season[16]. The flushing time of the estuary is around 6 to 7 tidal cycles during spring tide and around 23 to 45 tidal cycles during neap tide[17]. The estuary receives

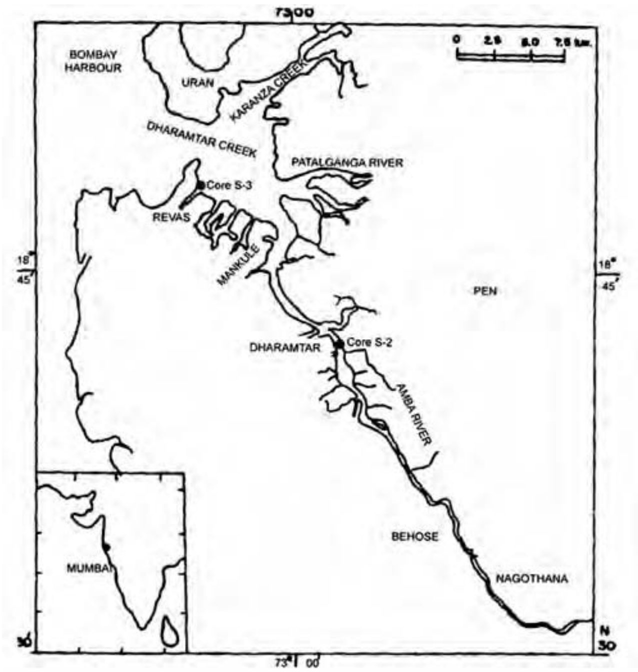

Fig. 1—Map of Study Area

substantial amount of waste water from a petrochemical complex and other industries that opens into Dharamtar creek[18].

Field Studies and Sampling

Sediment cores were collected from selected locations from two estuarine mudflats representing distinctive geomorphology and sedimentological settings within Dharamtar creek. Among the two cores, one near the mouth (S-3), not from the main channel of Dharamtar but from sub-channels viz. Revas Bandar and another from middle estuarine region (S-2). Cores were collected during low tide using hand driven PVC coring tube of 63 mm inner diameter. The core length varied between maximum of 82 cm in core S-2 and minimum of 46 cm in core S-3. Before sub-sampling, colour and texture was noted for both the cores. Cores were then sectioned at 2 cm interval with plastic knife to avoid metal contamination and were then placed in clean polythene bags and stored in ice-box till they were transferred to the laboratory.

Laboratory Analysis

The sediment was dried in petridish at 60°C for 48 hours. Sediment component analysis was carried out for all the sub-samples of both the cores by using Pipette method detailed by Folk[19]. Part of the dried sediment was finely powdered using agate-mortar and kept in pre-cleaned vials for the analysis of organic carbon (OC) and metals. Organic carbon was estimated using the method detailed[20] in which exothermic heating and oxidation with $K_2Cr_2O_7$ and concentrated H_2SO_4 are followed by titration of excess dichromate with 0.5 N $Fe(NH_4)_2(SO_4)_2.6H_2O$. Sediment samples for major (Al, Fe and Mn) and trace elements (Ni, Cr, Zn, Pb and Co) were digested using hydrofluoric-perchloric-nitric acid mixtures in Teflon beakers. Complete digestion was ensured by repeating the digestion steps until clear solutions were obtained. The concentrations of major and trace elements were determined using Varian AA 240 FS flame Atomic Absorption Spectrometry (AAS) with an air/acetylene flame for all of the above elements except for Al for which nitrous oxide/acetylene flame was employed at specific wavelengths. The instrument was calibrated by running blank and standard solutions prior to each element analysis. Recalibration check was performed at regular intervals. All chemicals used in the study were of analytical grade. Together with the samples, certified reference standard from the Canadian National Bureau of Standards (BCSS-1) was digested and run, to test the analytical and instrument accuracy of the method. The recoveries were between 86 and 91% for Fe, Ni and Al; 87-92% for Mn and Co; 80-85% for Pb and Zn; 90-95% for Cr, with a precision of +6%.

To evaluate anthropogenic influences of heavy metals in sediments, enrichment factor (EF) and geo-accumulation Index (I_{geo}) were calculated. Enrichment factor (EF) is the observed metal to aluminum ratio in the sample of interest divided by the background metal/aluminum ratio in the upper continental crust. It is expressed mathematically as:

$$EF= [(Me/Al)_{sediment}/(Me/Al)_{ucc}]$$

Where, $(Me/Al)_{sediment}$ is the metal to Al ratio in the sample of interest and $(Me/Al)_{ucc}$ is the background value of metal to Al ratio[21]. The average Al concentration[22] as the background value in upper continental crust has been used in the computations. The index of geo-accumulation has been computed using the formula of Muller[23], given below.

$$I_{geo} = log_2\ C_n/1.5*B_n$$

Where, I_{geo} is Index of geo-accumulation, *Cn* is measured concentration of element *"n"* and *Bn* is element content in "average shale"[24] and the factor 1.5 is used because of possible variation of the background data due to lithogenic effects.

Results and Discussion

The cores can be separated into following zones based upon the differences in colour:

1. A uniform grey colour from 0 to 46 cm in core S-3.
2. A uniform grey from 0 to 25 cm and mixed black and grey colour from 25 to 82 cm in core S-2.

The sediments are mainly composed of silt and clay (<63 mm) contributing greater than 90% in both the cores, indicating relatively calm environment of deposition prevailed during the deposition of sediments. The data showed a range of 0.42% to 2.76% with a mean of 1.07% sand, 41.57% to 65.15% with a mean of 52.39% silt and 33.96% to 57.76% with a mean of 46.53% clay for core S – 3 collected near the mouth and 1.54% to 23.67% with a mean of 7.87% sand, 26.8% to 55.34% with a mean of 34.09% silt and 40.64% to 67.64% with a mean of 58.04% clay for core S-2 collected at mid estuarine region.

The core collected near the mouth (S-3), can be divided into three portions viz., lower (46 cm to 28 cm), middle (28 cm to 6 cm) and upper (6 cm up to surface). In the lower portion, sand and silt shows nearly similar distribution pattern. Clay compensates distribution of silt and sand. At 30 cm depth sand and silt show major positive peak which is compensated by negative peak of clay. In the middle region, sand and silt show gradual decrease with silt displaying larger fluctuations. The fluctuating decreasing trend of silt is compensated by increasing trend of clay (Fig. 2a). In the upper portion sand and silt show increasing trend and clay shows decreasing trend. Distribution of sediment components (sand, silt and clay) along the length of the core is important in understanding the source, transport, history and process of sediments. Presence of higher percentage of finer sediments at this location can be attributed to two main reasons: first construction of jetty near Revas Bandar which reduced the tidal flow and second dredging of main channel of the harbour and the dumping of these finer sediments in the adjoining area[16].

The core collected from middle (S-2) region of the estuary, can also be divided into three portion viz. lower (82 cm to 60 cm), middle (60 cm to 42 cm) and upper (42 cm up to surface). In the lower portion, sand shows high values with gradual decrease (20.68% to 7.19%) from 82 to 74 cm and gradual increase (7.19% to 23.67%) from 74 cm to 60 cm. Clay displays greater fluctuations and compensates both silt and sand. In the middle portion, clay and sand compensates each other (Fig. 2b) indicating deposition of sediments in phases and pulsating supply of fine and coarse sediments into the tidal flats. Strong tidal currents in the study area[13] are

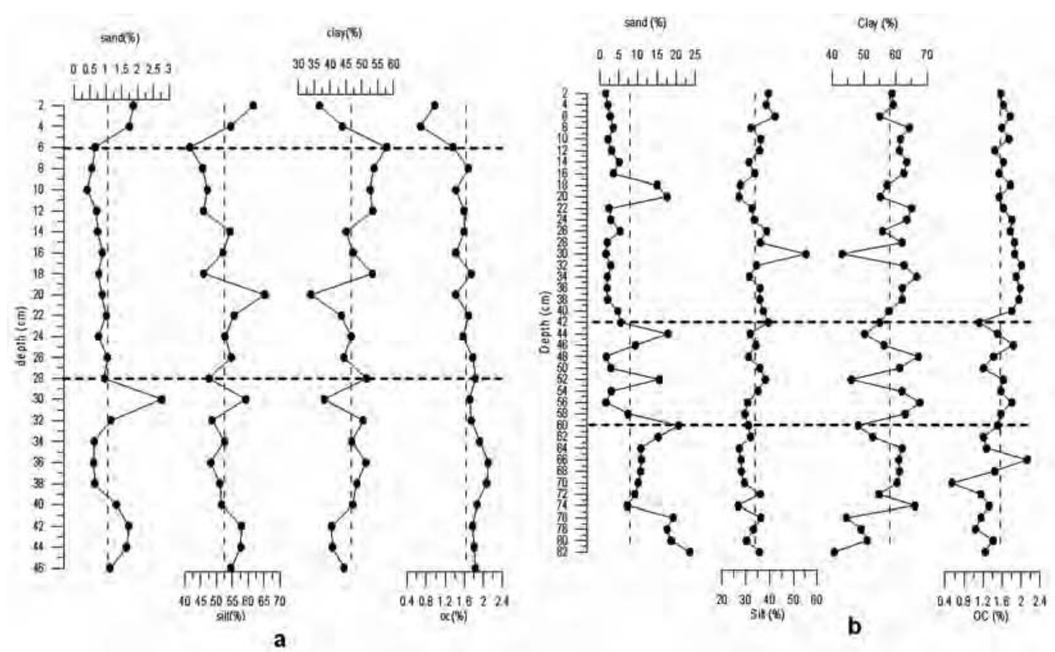

Fig. 2a,b—Downcore variations of sediment components and organic carbon with vertical lines of average value in core S-3 (a) and S-2 (b) responsible for re-suspension of fine sediments and flush out the material to the open ocean, thus leaving coarser sediment as bed load lag deposits. This must have resulted in beds with coarser sands in the upper reaches[25]. Alternatively this region receives an average of 2100 mm rainfall of which 95% occurs during monsoon period[14]. Both varying rainfall and runoff must be responsible for the formation of sediment beds with coarser sediments between finer sediments. Silt fluctuates around average line. In the upper portion, sand shows low and slightly decreasing trend except a major peak at 20 cm depth. Silt and clay largely compensates each other with few fluctuations. Major positive peak of silt at 30 cm depth is compensated by major negative peak of clay.

A number of approaches to classify the sediments, in order to understand the depositional environment have been proposed e.g., a simplified classification of intertidal Wadden Sea sediments on the basis of sand/mud ratios[26], a hydrodynamic based classification of fine-grained estuarine sediments using sand/silt/clay ratios[27], a classification for coarse-grained sediments based on gravel/sand/mud ratios[28], or attempts to classify sediments by multivariate analyses, e.g. clustering techniques using three-component mixtures[29].

In this paper, sediment classification proposed by Flemming[30] has been used plotting the percentage of sand, silt and clay in a triangular diagram and hydrodynamic based classification of Pejrup[27], in order to understand the changing sediment character throughout the core.

The data when plotted on ternary diagram by Flemming[30] it is found that cores S-3 (near mouth) and S-2 (middle estuarine region) can be divided into different zones (Fig. 3) as shown below.

Core S-3 (near mouth)		Core S-2 (middle region)	
Depth (cm)	Lithology	Depth (cm)	Lithology
0 – 46	Mud	0 – 42	Mud
		42 – 82	Slightly sandy mud

Ternary diagram by Pejrup[27] modifies and expands Folk's diagram[31] on the basis of hydrodynamic conditions. The lines separating the four hydrodynamic groups, being used to highlight the energy gradient from lower (clay-dominated mud) to higher energy levels (silt dominated mud). Pejrup[27] has interpreted that section I indicates very calm hydrodynamic conditions rarely found in estuaries and sections II to IV indicate increasingly violent hydrodynamic conditions.

The plot reveals that the core S-3 collected from the lower estuarine region falls within section II, indicating that the sediments here have deposited in less violent conditions. Core S-2, which was collected from the middle estuarine region, falls within sections II and III, indicating relatively violent to less violent hydrodynamic condition (Fig. 4). This may be due to dynamic environment formed by the interaction of marine and fresh waters in the middle estuarine region.

Organic carbon ranges from 0.68% to 2.10% with a mean value of 1.63% for core S-3 and 0.55% to 2.13% with a mean value of 1.58% for core S-2. In the core collected near the mouth (S-3), in the lower portion (46 cm – 28 cm), organic carbon shows slightly high values than average line and the distribution is largely in agreement with that of clay distribution. High content of organic carbon in this portion must be due to high supply of refractory organic matter[32]. In the middle portion (28 cm – 6 cm), organic carbon shows gradual decrease (Fig. 2). In the upper portion (6 cm – surface) organic carbon shows very low values ranging between 0.68% and 1.68%. This can be attributed mainly to the constant flushing activity by tides and waves[33] which mobilizes litter and leaches out organic matter near the mouth.

In the core collected from the middle estuarine region, in the lower portion (60 cm – 82 cm) organic carbon shows low fluctuating values and a peak at

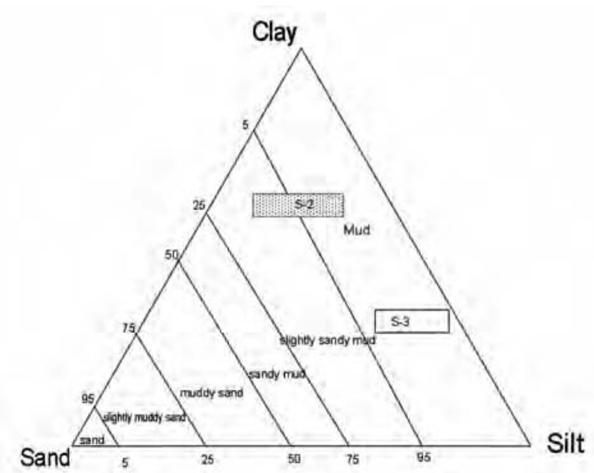

Fig. 3—Ternary diagrams for a revised textural classification of sediments on the basis of sand / mud ratios after Flemming (2000)

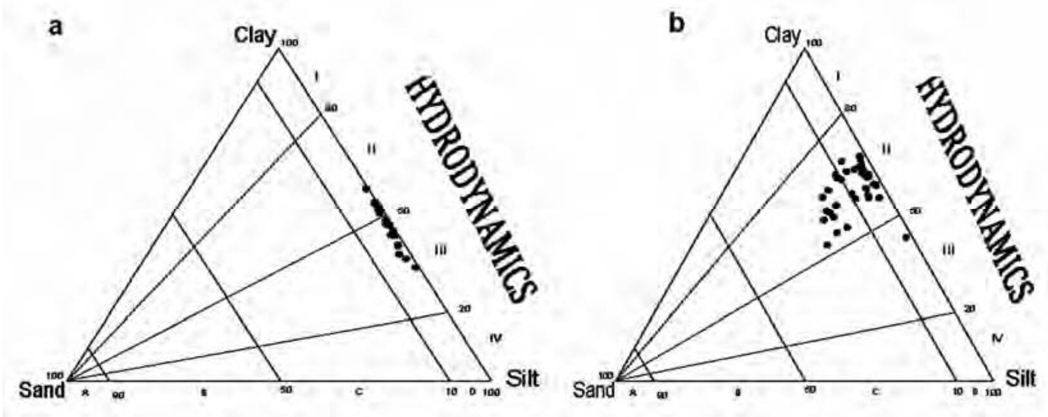

Fig. 4a,b—Triangular diagram for the classification of hydrodynamics after Pejrup (1988) for core S-3 (a) and S-2 (b)

66 cm depth. Low organic carbon content is related to the poor absorbability of organics on negatively charged quartz grains[34], which predominate in this portion. Clay is also lesser in this portion. In the middle portion (42 cm – 60 cm), organic carbon values fluctuates around average line, peak values agrees with that of clay distribution. In the upper portion (42 cm – surface) organic carbon shows relatively higher values and the distribution is largely similar to that of clay. The higher organic carbon in this portion is due to additional supply of terrestrial organic matter[35] in the recent years.

In core S-3 which was collected near the mouth, Fe ranges from 7.83% to 9.32% with a mean value of 8.44%; the Al concentration ranges from 7.85% to 10.06 with a mean value of 9.43% and Mn ranges from 646 ppm to 828 ppm with a mean value of 727 ppm. In the lower portion, Al and Fe show gradual increasing trend whereas Mn shows decreasing trend up to 38 cm and then shows positive peak at 30 cm depth. Fe, silt and sand also display peak value at this depth. In the middle portion, Al fluctuates around average line. Fe and Mn show low values except for two positive peak values of Fe at 24 cm and 16 cm depth (Fig. 5a). In the upper portion, Fe, Mn, sand and silt have fairly similar distribution patterns of enrichment near surface which might be due to the early diagnetic remobilization[36-37] stated that Fe^{+2} and Mn^{+2} species get precipitated in the top layers in the sediments as these elements diffuse upward from subsurface. This must have resulted in lower values of Fe and Mn in the middle portion of the core.

In core S-2 collected from middle regions of the estuary, Fe ranges from 7.00% to 8.63% with a mean value of 7.6%; the Al concentration ranges from 6.71% to 8.93% with a mean value of 8.23% and Mn ranges from 694 ppm to 923 ppm with a mean value of 795 ppm. In the lower portion of the core, Al shows lower concentration than average line which is governed by low content of finer fraction in this portion as Al is mostly associated with aluminosilicates. Fe in deeper layer (82 cm to 68 cm) displays high values which agrees with the distribution of sand fraction (>63 µm). Mn distribution in this portion is similar to that of Fe (Fig. 5b). In the middle portion, the trends of Fe and Mn are similar, reflecting similar source and/or post-depositional behaviours. Peak value of Fe and Mn at 52 cm depth coincides with that of sand at same depth. Al shows gradual increase between 60 cm and 54 cm and decrease from 54 cm to 42 cm. In the upper portion, distribution of Al largely agrees with that of clay. Fe fluctuates around average line and shows higher values in upper part of upper portion of the core. Mn near the surface shows gradual decrease. This must be due to removal of Mn from sediment to water for biotic uptake[38].

In core S-3 Ni concentration ranges from 88 ppm to 127 ppm with a mean value of 103 ppm; Cr varies from 271 ppm to 352 ppm with a mean value of 292 ppm; Pb ranges from 7 ppm to 121 ppm with a mean value of 70 ppm; Co concentration ranges from 46 ppm to 63 ppm with a mean value of 55 ppm and Zn varies from 124 ppm to 144 ppm with a mean value of 133 ppm. The average values of heavy metal concentrations displayed the following order, Cr > Zn > Ni > Pb > Co. Pb displayed overall increasing trend and Co showed decreasing trend in the lower portion. Other elements maintained almost constant values. In the middle portion Ni and Pb and to some extent Cr showed gradual increasing trend whereas Co and Zn

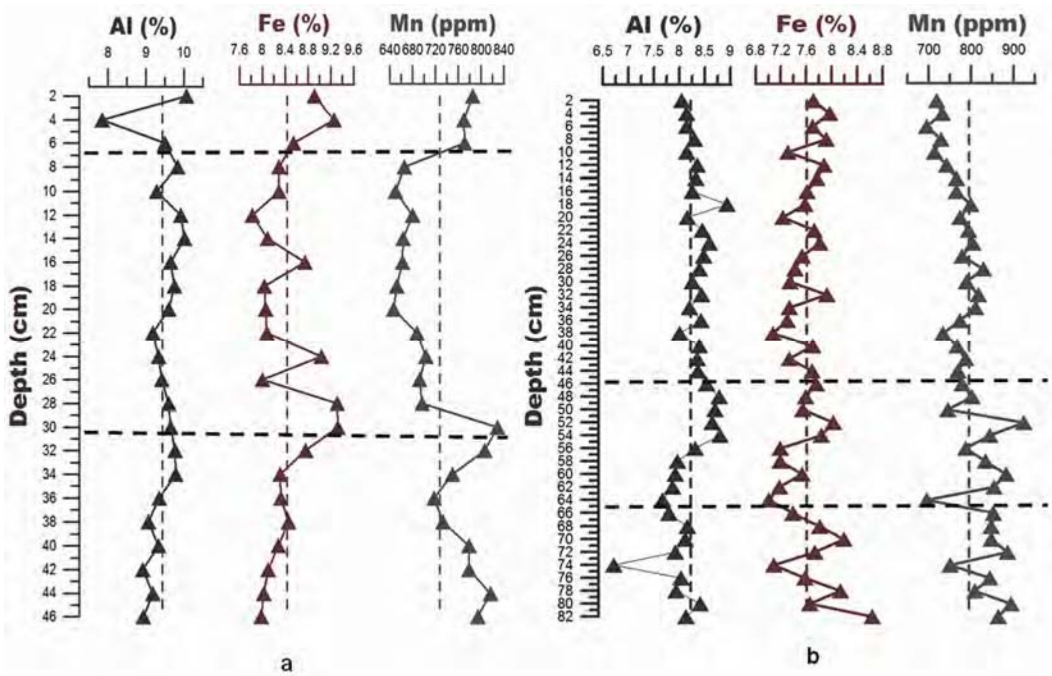

Fig. 5a,b—Downcore variations of major elements with vertical lines of average value in core S-3 (a) and S-2 (b)

showed decreasing trend (Fig. 6a). In the upper portion most of the elements except for Co showed higher values. High value of most of the elements in the upper portion indicates that their redistribution is controlled by Fe and Mn oxyhydroxides and trapping of these elements in aerobic conditions[39].

In core S-2 Ni ranges from 81 ppm to 113 ppm with a mean value of 96 ppm; Cr ranges from 117 ppm to 322 ppm with a mean value of 245 ppm; Pb ranges from 44 ppm to 133 ppm with a mean value of 87 ppm; Co ranges from 59 ppm to 81 ppm with a mean value of 71 ppm and Zn concentration ranges from 112 ppm to 218 ppm with a mean value of 136 ppm. The average values of heavy metal concentrations displayed the following order, Cr >Zn > Ni >Pb >Co. The metal concentrations of Ni, Co and Cr do not show much fluctuation with depth (Fig. 6b). The Pb profile shows gradual increase in lower, middle portions and higher values in the upper portion. Zn exhibits almost constant trend in lower, middle portions and also lower part of upper portion. Zn in the upper part of upper portion i.e from 20 cm to surface shows increasing trend. Peak values obtained at 52 cm and 24 cm depth for Ni, Co and Cr coincides with that of Fe and Mn suggests reprecipitation of trace metals on Fe/Mn oxides and oxyhydroxides coatings[40-41,9]. have also reported that the concentration of metals below the oxic-suboxic interface is controlled by Fe and Mn oxyhydroxides. Higher concentration of Ni, Co and Cr in the lower portion also agrees largely with that of Fe and Mn distribution. Low organic carbon content in the lower portion causes the redox cycling of the metals to occur relatively deep in the core sediments[42]. Increased and high values of Pb and Zn in the upper portion are attributed to enhanced anthropogenic supply of these elements. These elements are preserved as adsorption on the finer fraction of sediments and not due to precipitation on Fe and Mn oxy-hydroxides or complexation with organic matter[43] as distribution trend of Fe and Mn and organic carbon decreases towards surface in the upper portion.

When two locations are compared, higher content of finer sediments are deposited near the mouth. Organic carbon concentration was found to be relatively higher near mouth, which is associated with finer sediments and deposited in calm environment. High values of Fe at surface/subsurface layers (0-10 cm) in core S-2 and S-3, could be mainly attributed to industrial plants and activities of the port around Dharamtar. The materials carried by the barges around industries are the main sources for Fe which settle down and mix with the bottom sediments in these regions. The precipitated Fe in the form of oxyhydroxides has the affinity to scavenge other metals such as Ni, Pb, Cr etc., as they pass through the water en route to the sediment[44]. Al exhibit high concentration (up to 10%) in core S-3 which can

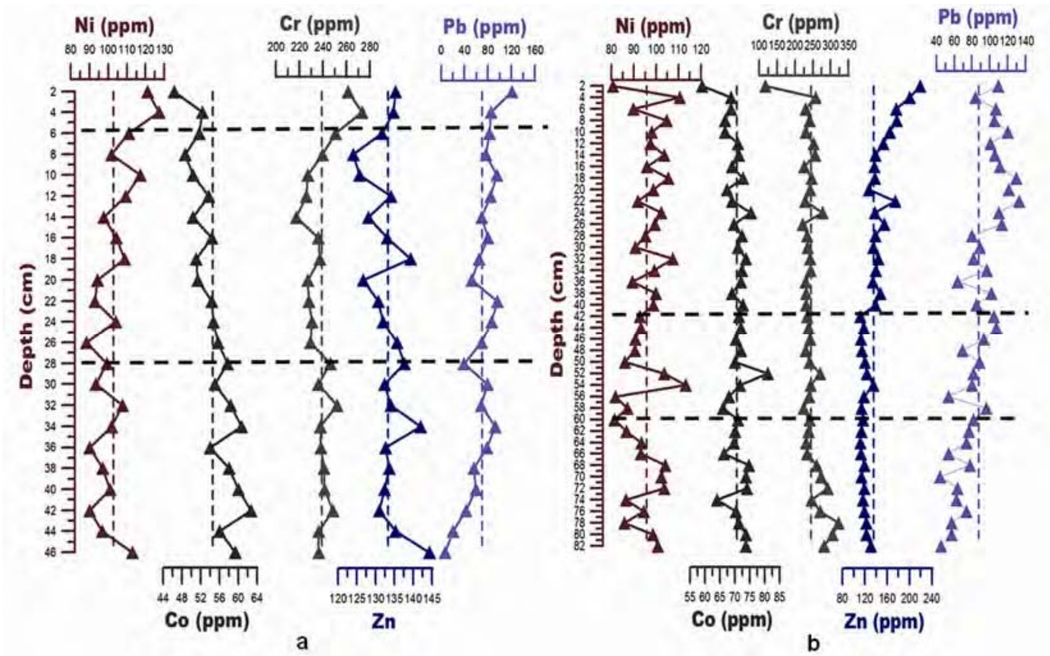

Fig. 6a,b—Downcore variations of trace elements with vertical lines of average value in core S-3 (a) and S-2 (b)

be attributed to various factors such as active bioturbation along with tidal influenced back water, larger removal rates of detrital material and also Al is mostly associated with finer sediments (mud constitutes up to 99%).

In core S-3, major elements namely Fe and Mn show good positive correlation with Co and Cr and weak correlation with Zn, Pb and Ni (Table 3a). In core S-2, Fe and Mn show good positive correlation with most of the elements except Pb and Zn (Table 3b). The positive correlation of Fe and Mn with metals suggests that Fe-Mn oxyhydroxides are the main geochemical carriers these metals. Al show weak correlation with most of the elements in both the cores indicating that metal enrichment observed in the sediments likely to originate from distinct source to that of Al. The coarser sand fraction show good positive correlation with Fe and Mn in core S-3 and with Mn and Co in core S-2. Finer silt and clay fraction and organic carbon show no significant correlation with metals. Thus the sediment component along with organic carbon seems to exert only partial influence on the geochemical distribution.

The average concentration of trace metals for the present work were compared with those obtained from nearby Manori creek[11] (towards north of Dharamtar) and Mandovi Estuary[45] in Goa, west coast of India. Ni, Cr, Co and Pb showed maximum concentration in Dharamtar creek indicating that Dharamtar creek is more polluted with respect to these metals than Manori creek and Mandovi Estuary. The high concentration of these pollutants in Dharamtar creek could mainly be attributed to the materials released from upstream of Dharamtar and transported in the inner estuary during spring flood tide and is not flushed out following the ebb[17]. Further it could be also due to riverine flow during monsoons which builds up pollutants

As stated earlier, metals associated with sediments are released into the aquatic environment by two main sources viz natural and anthropogenic. Natural sources mainly results from erosion of ore bearing rocks, wind blown dust and volcanic activities, whereas anthropogenic sources include discharge of agricultural, municipal or industrial waste[3,46]. Classified level of pollution using enrichment factor (EF) as extremely severe (EF>50), Very severe (25-50), severe (10-25), moderately severe (5-10), moderate (3-5), minor (1-3) and no enrichment (EF<1). The data computed shows EF value for Cr in both the cores falls in the range between 5 and 10 indicating moderately severe enrichment. EF value for Ni in core S-3 (in lower and middle portion) and S-2 fall in the range between 3 and 5 indicating moderate enrichment of these elements (Table 1). Ni in the upper portion in core S-3 falls in the range between 5 and 10. EF value for Pb in core S-3 (in middle and upper portion) and core S-2 (in lower and middle portion) falls in the range between 3 and 5 indicating moderate enrichment. Pb in the lower portion in core S-3 falls in range between 1-3 and core S-2 in the upper portion falls in the range between 5 and 10. EF value for Mn, Zn and Fe in both the cores falls in the range between 1 and 3 indicating minor enrichment. EF value for Co in core S-3 falls in the range between 3 and 5 and in core S-2 falls in the range between 5 and 10. Almost all the metals in core S-3 shows maximum enrichment at the upper portion indicating increase in level of pollution over the recent years.

Muller[23] classified the intensity of pollution into seven classes based upon Index of geo-accumulation (Igeo) values viz "very strongly polluted" - Igeo class 6 (Igeo >5); "Strong to very strong" - Igeo class 5 (Igeo 4-5); Strongly polluted - Igeo class 4 (Igeo 3-4); "Moderately to strongly polluted" - Igeo class 3 (Igeo 2-3); "Moderately polluted" - Igeo class 2 (Igeo 1-2); "Unpolluted to moderately polluted" - Igeo class 1 (Igeo 0-1) and "Unpolluted" - Igeo class 0 (Igeo <0). From the data computed, Igeo value for Pb in core S-3 (in upper and middle portion) and S-2 falls in Igeo class 2. Igeo value for Co in core S-3 (in lower portion) and core S-2 falls in class 2 indicating moderate pollution of Pb and Co. Pb (in lower portion) and Co (in middle and upper portion) in core S-3 falls in class 1 reflecting an increase in Pb contamination and decrease in Co contamination over the years. Fe in both the cores falls in Igeo class 1 (Table 2). Igeo value for Cr in core S-3 (in lower and

Table 1—The mean Enrichment factor (EF) of different metals in core S-3 and S-2.

Core S-3	EF(Fe)	EF(Mn)	EF(Cr)	EF(Ni)	EF(Co)	EF(Pb)	Zn(EF)
Upper(0-6cm)	2.48	1.26	6.43	5.54	3.72	4.78	2.21
Middle(6-28cm)	2.19	1.04	5.38	4.45	3.68	3.55	2.04
Lower(28-46cm)	2.27	1.21	5.71	4.41	4.16	2.60	2.16
Core S-2	EF(Fe)	EF(Mn)	EF(Cr)	EF(Ni)	EF(Co)	EF(Pb)	EF(Zn)
Upper(0-42cm)	2.28	1.35	6.21	4.88	5.61	5.60	2.72
Middle(42-60cm)	2.25	1.42	6.31	4.53	5.65	4.62	2.09
Lower(60-82cm)	2.44	1.56	7.46	4.97	6.02	3.70	2.23

Table 2—The mean Geoaccumulation index (Igeo) of different metals in core S-3 and S-2.

Core S-3	IgeoFe	IgeoMn	IgeoCr	IgeoNi	IgeoCo	IgeoPb	IgeoZn
Upper(0-6cm)	0.33	-0.22	1.07	0.23	0.81	1.65	-0.09
Middle(6-28cm)	0.24	-0.41	0.90	0.00	0.89	1.27	-0.12
Lower(28-46cm)	0.26	-0.23	0.95	-0.05	1.03	0.56	-0.07
Core S-2	IgeoFe	IgeoMn	IgeoCr	IgeoNi	IgeoCo	IgeoPb	IgeoZn
Upper (0-42cm)	0.10	-0.23	0.89	-0.07	1.29	1.75	0.07
Middle(42-60cm)	0.09	-0.15	0.95	-0.16	1.32	1.48	-0.27
Lower(60-82cm)	0.11	-0.11	1.09	-0.12	1.32	1.06	-0.27

Table 3a—Pearson correlation between different sediment components (sand, silt, clay and organic carbon) and elements in core S-3

	Sand	Silt	Clay	OC	Al	Fe	Mn	Ni	Cr	Co	Zn	Pb
Sand	1.00											
Silt	0.60	1.00										
Clay	-0.66	-1.00	1.00									
OC	-0.25	-0.21	0.22	1.00								
Al	-0.22	-0.13	0.14	0.24	1.00							
Fe	0.42	0.03	-0.07	-0.38	-0.14	1.00						
Mn	0.71	0.25	-0.30	0.02	-0.28	0.31	1.00					
Ni	0.00	-0.22	0.21	-0.71	-0.19	0.30	0.11	1.00				
Cr	0.41	-0.01	-0.02	-0.47	-0.43	0.57	0.56	0.52	1.00			
Co	0.14	0.05	-0.06	0.59	-0.30	-0.07	0.44	-0.39	0.03	1.00		
Zn	0.15	0.00	-0.01	0.20	-0.11	0.04	0.40	0.18	0.25	0.46	1.00	
Pb	-0.09	-0.11	0.11	-0.47	0.27	0.28	-0.23	0.30	0.11	-0.54	-0.31	1.00

Table 3b—Pearson correlation between different sediment components (sand, silt, clay and organic carbon) and elements in core S-2

	Sand	Silt	Clay	OC	Al	Fe	Mn	Ni	Cr	Co	Zn	Pb
Sand	1											
Silt	-0.34	1										
Clay	-0.71	-0.42	1.00									
OC	-0.43	0.20	0.27	1.00								
Al	-0.19	0.22	0.02	0.25	1.00							
Fe	0.25	0.12	-0.33	-0.28	0.32	1.00						
Mn	0.54	-0.16	-0.41	-0.20	0.11	0.29	1.00					
Ni	-0.04	-0.02	0.06	0.09	0.35	0.43	0.15	1.00				
Cr	0.48	-0.18	-0.32	-0.36	0.00	0.39	0.50	0.36	1.00			
Co	0.28	0.05	-0.31	-0.10	0.47	0.42	0.59	0.48	0.65	1.00		
Zn	-0.48	0.38	0.18	0.32	0.12	0.21	-0.52	0.17	-0.48	-0.42	1.00	
Pb	-0.30	0.15	0.18	0.35	0.33	-0.18	-0.47	0.11	-0.44	-0.23	0.50	1.0(

middle portion) and core S-2 (in middle and upper portion) falls in class 1 indicating that sediments are unpolluted to moderately polluted from these metals. Cr in core S-3 (in upper portion) and core S-2 (in lower portion) falls in Igeo class 2 reflecting that surface and bottom sediments of core S-3 and S-2 are moderately contaminated. Mn in both the cores falls in Igeo class 0. Igeo value for Zn in core S-3 and S-2 (lower and middle portion) falls in Igeo class 0 indicating that sediments are unpolluted with Mn. Igeo value for Ni in core S-3 (lower and middle portion) and Ni in core S-2 also falls in class 0. In the upper portion of core S-3, Ni and Zn (in core S-2) falls in Igeo class 1 reflecting an increase in contamination with respect to these metals in recent past.

Conclusion

The sediments of Dharamtar creek are classified as mud in the upper 42 cm in both the cores indicating that the estuary provides similar depositional environment in the recent years in its estuarine limits. The distribution of metals is largely controlled by sediment components, organic carbon and Fe-Mn oxyhydroxides at both near the mouth and in the middle regions of the creek. When the average values are considered, Mn and Co shows higher concentration in middle estuarine regions whereas, Fe along with Al shows higher concentration near the mouth. Geo-accumulation index computed for the metals indicate that Dharamtar creek is moderately polluted with Pb and Co, unpolluted to moderately polluted with Ni, Cr and Fe and practically unpolluted with Zn and Mn source being both natural and anthropogenic. Enrichment factor near mouth indicates increase in the level of pollution over the recent years.

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