Geochemical Assessment in a Creek Environment in Mumbai, West Coast of India

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To understand the status of metal pollution, various sediment parameters such as organic matter, sediment composition and heavy metal concentrations were analyzed at the head and mouth end of a creek in western Mumbai, India. High metal concentrations were observed at the inner creek-(head)-end, characterized by the presence of finer sediments and higher organic matter as compared to near the mouth of the creek. Geochemical indices employed to determine the pollution status of the region, showed that the creek is moderately polluted with Cu and Pb. Increase of Pollution Load Index (PLI) in the upper portions of both the cores, representing recently settled sediments, supports the influence of external discrete anthropogenic sources like agricultural runoff, industrial and atmospheric inputs. The mean concentrations of most elements exceed the threshold effect level (TEL), probable effect level (PEL) and effects range low (ERL) values indicating that, there may be ecotoxicological risk to sediment dwelling organisms.

Keywords: metals, pollution indices, creek, Mumbai, anthropogenic

The sea and more particularly the smaller aquatic systems like estuaries and creeks are the ultimate repositories of waste generated and released to the environment by the human population. Generally, the level of pollution of an aquatic ecosystem is assessed by analyzing the physico-chemical parameters of water. However, heavy metal contents in sediments are an accepted and widely used indicator of anthropogenic pollution over time (Nriagu, 1996; Rognerud and Fjeld, 2001). Heavy metals are stable and persistent environmental contaminants of coastal waters and sediments, being from either lithogenic or anthropogenic sources or both. The primary lithogenic sources include chemical leaching of bedrocks, water drainage basins and runoff from banks, whereas discharge of urban and industrial waste water, combustion of fossil fuels, mining and smelting operations, processing and manufacturing industries, agricultural outputs and waste disposal including dumping are examples of anthropogenic pollution sources (Klavins et al., 2000; Pardo et al., 1990; Yu et al., 2001). Anthropogenic trace metals in estuarine and coastal marine sediments are often introduced initially to the environment in solution form, which with time tend to get adsorbed on suspended sediments and on inorganic and organic colloidal particles. The adsorption and consequent sedimentation of metals mainly depend on the sediment composition including grain size, carbonate content, organic matter and Fe-Mn oxyhydroxides. Each sediment layer forms as a result of a prolonged sedimentation process and tends to accumulate most of the heavy-metal pollutants over time and does not undergo any sudden change. Analysis of sediment cores, therefore, enables us to gain an integrated picture of the contaminant load with time.

Manori, a tidally influenced creek in western Mumbai, India is increasingly affected by heavy siltation due to the flushing of polluted waters from the nearby industrial, residential areas, and slums (Quadros 2002; Quadros et al., 2001). Further, the untreated or partially treated sewage is deteriorating the environmental quality of the creek. A few spatial studies on the physico-chemical characteristic of the waters of Manori are available. However, temporal studies on the status and accumulation of metal concentration over the years in the sediment of the creek are rare. Therefore, the primary purpose of the present study was to determine the spatial distribution pattern and also understand the temporal concentration levels of sediment components and selected metals (Fe, Mn, Cu, Pb, Co, Ni, Zn, Cr, and Al) through sediment cores collected from the intertidal regions of Manori Creek, thereby assessing the pollution status and the possible influence of anthropogenic activities in the region.

MATERIALS AND METHODS

Study Area

The study is focused on Manori Creek, which extends between $19°11'$N, $72°47'$E and $19°15'$N, $72°50'$E, and lies on the west coast of India. Its total length is around 10 km. The region receives an average rainfall of 2470 mm, around 90% of which is found to precipitate during the monsoon season spanning between July and August. The creek experiences pronounced cycle of freshwater flow during the monsoon, which becomes negligible after September. The tides in the region are semidiurnal

with spring and neap ranges of 3.5 m and 1.8 m respectively in the mouth area that induces good tidal flushing of the lower reaches. The creek is drained by the River Dahisar and is characterized by mangroves, mudflats and low-lying marshy areas. The downstream region, at the northern bank of the creek, is bordered by a village called Manori, while the upstream region is called the Gorai Creek. At the southern bank of the creek lies a coastal strip having a landscape of fine beaches. A number of ferries and fishing boats operate in the region. Until the 1980s, Gorai was known for its clean beaches and palm trees. In recent years, with the increase in human population and its influence on surrounding areas, its beaches have become unfit for recreation. It is important to mention here that the Essel World, Asia's largest amusement park, lies in Gorai.

Sample Collection

Two sediment cores of 42 and 50 cm lengths were collected from the intertidal regions, representing the mouth (M2) (latitude $19^011'42.2''$N and longitude $72^048'05.4''$E) and head (M1) (latitude $19^014'01'$N and longitude $72^049'25''$E) region of the creek (Figure 1), with the help of 150 cm long PVC tubes. At the seaward end, the creek is around 1 km wide and shallow (0.8 to 4 m) and runs for a length of $\sim$10.6 km towards the inner end (Kulkarni et al., 2010). Considering the small area of the creek, only two sediment cores were sampled for the present study which likely represents the creek environment to a good extent. The cores were transported to the laboratory, sectioned at 2 cm intervals and kept at low temperature ($4°$C) till further analysis.

Laboratory Analyses

Sedimentological analysis was carried out by drying the sediment samples in an oven at $60°$C and then disaggregating the samples. The standard pipette technique (Folk, 1974) was used to determine the sand and mud (silt and clay) percentage (grain size), for each of the sub-samples. For geochemical analysis, the dried sediment samples were ground into a fine powder with an agate mortar and pestle. Total organic carbon was measured applying a widely used standard technique based on rapid dichromate oxidation and back titration with ferrous ammonium sulphate (Walkley and Black, 1934). For total phosphorus (TP) and total nitrogen (TN) in sediment, the standard procedure (Grasshoff, 1999) was employed. For the metal analysis, 0.2 g of each sediment sample was digested using a $HF-HClO_4-HNO_3$ acid mixture (Jarvis and Jarvis, 1985). Metals were determined by flame atomic absorption spectrophotometry (240FS-AA) using a Varian model Spectra-AA spectrophotometer. The concentrations of selected elements namely Fe, Mn, Cu, Pb, Co, Ni, Zn, and Cr were measured with an air–acetylene flame, while a nitrous oxide-acetylene flame was employed for Al. Suitable internal chemical standards (Merck Chemicals) were used to calibrate the instrument. Also, a recalibration check was performed at regular intervals. A standard reference material
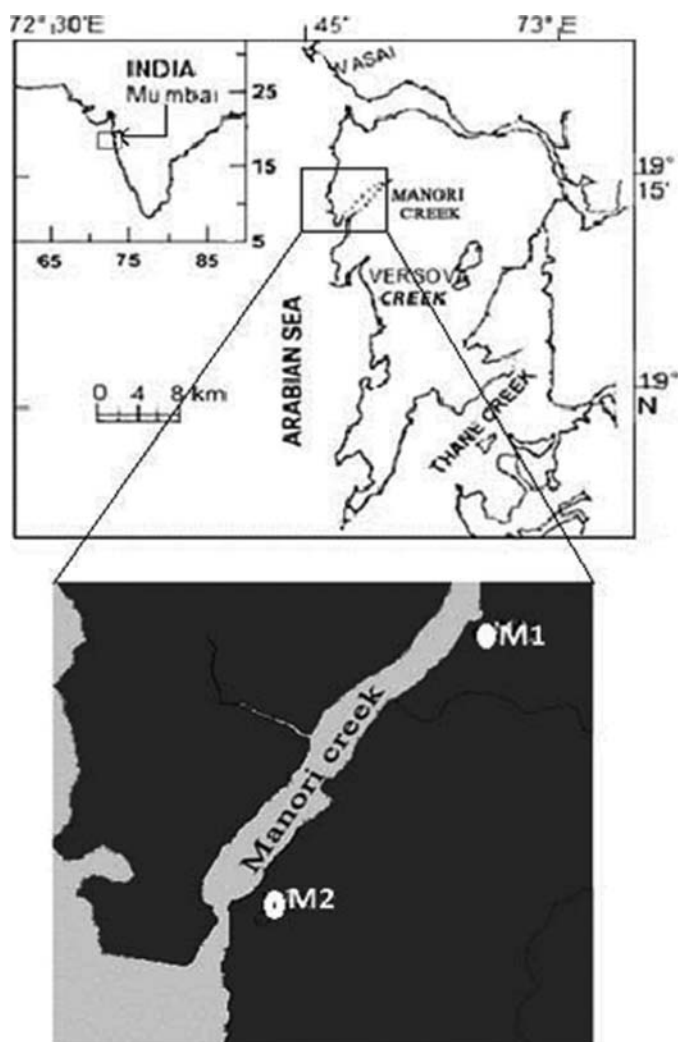
Figure 1. Map of the studied area showing the location of cores.

(BCSS-1) was also digested and analyzed in a similar way to ensure quality control and accuracy of the analysis. The recoveries were between 86%–91% for Fe, Cu, Ni and Al; 87%–92% for Mn and Co; 80%–85% for Pb and Zn; 90%–95% for Cr with a precision of +6%. The software Statistica 6.0 (Varian Put Ltd., Australia) was employed to carry out correlation analysis of the obtained data. It should be mentioned here that since the subsamples were of a small number (approximately 20–25), some of the correlations might be significant by chance.

RESULTS AND DISCUSSION

Grain Size and Organic Matter Content

The range and mean values of sediment composition along with organic matter for cores M1 and M2 are presented in Figures 2a and 2b. The percentage of sand, silt and clay are found to vary from 0.46%–4.41%, 25.77%–47.40% and 51.23%–71.94% with mean values of 1.51%, 40.49% and 58% respectively for core M1, which was collected near the head region of the creek.
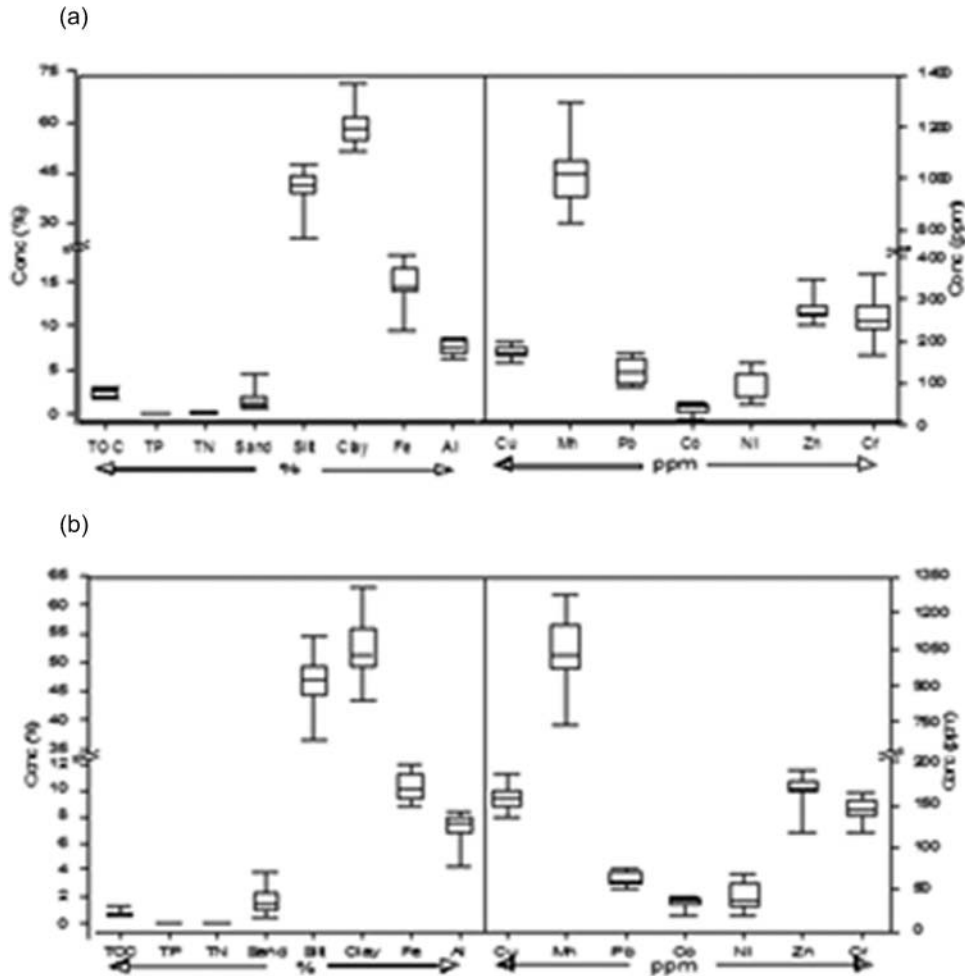
Figure 2. Box and Whisker plots of heavy metal concentrations in a) M1 and b) M2 (The horizontal bar in the box displays the mean value, the ends of the Whiskers to the maximum and minimum values. The top and bottom of the boxes include half the data points between the average and the extremes of the range).

For core M2, collected near the mouth region of the creek, the percentage of sand, silt and clay are observed to range from 0.33%–3.90%, 36.69%–54.32% and 43.57%–62.80% having mean values of 1.60%, 46.45% and 51.95%, respectively, for the corresponding sediment components. In the case of total organic carbon (TOC), higher content in the range of 2.00%–3.02% with a mean value of 2.39% is seen for core M1 than for core M2 which shows a range from 0.52%–1.28% and a mean value of 0.73%. Similarly, higher values varying from 0.40–1.12 mg/g with a mean of 0.81 mg/g and 0.28–2.99 mg/g and a mean of 1.62 mg/g are also seen for TP and TN in core M1 than core M2, which shows comparatively lower values ranging from 0.20–0.80 mg/g for TP and 0.73–2.03 mg/g for TN having corresponding means of 0.54 mg/g and 1.35 mg/g, respectively.

Metal Distribution

The range along with the mean values of metal concentrations for M1 and M2 are shown in Figures 2a and 2b. Fe was the most abundant element in the study area, followed by Al. In

core M1, almost all the studied elements are found to be much higher than in core M2. In general, the overall abundance of metal concentrations in the sediments of both the cores follows the order:

$$Fe > Al > Mn > Zn > Cr > Cu > Pb > Ni > Co \quad (EQ1)$$

Correlation Coefficient

Core M1 (Table 1) shows significant correlations of TN and good correlations of TOC with metals such as Ni, Cr and Al while in core M2 (Table 2), organic matter (TOC, TP and TN) is found to show good associations with Cu, Mn, Pb, Ni, and Zn. The comparatively lower metal values seen at M2 indicates that the higher metal concentrations seen at M1 are diluted by seawater at M2. These observations reflect an anthropogenic origin for metals at M1 which are transported by the current to M2 during ebb tides. No significant correlations are observed for Fe and Mn with other metals in both the cores, except for Pb with Fe in core M2. This findings indicates that the metals in

Table 1. *Pearsons correlation coefficients for sediment component, organic matter and selected elements in core M1 (p<0.05; n = 25)*

	TOC	TP	TN	Sand	Silt	Clay	Cu	Fe	Mn	Pb	Co	Ni	Zn	Cr	Al
TOC	1.00														
TP	0.35	1.00													
TN	**0.56**	0.40	1.00												
Sand	0.26	−0.04	0.21	1.00											
Silt	−0.05	−0.09	−0.27	−0.07	1.00										
Clay	0.00	0.10	0.23	−0.12	−0.98	1.00									
Cu	0.18	−0.16	−0.24	−0.17	0.22	−0.18	1.00								
Fe	0.05	**−0.41**	0.02	0.22	−0.16	0.12	−0.14	1.00							
Mn	0.16	−0.11	−0.12	0.25	**0.51**	**−0.56**	−0.04	−0.18	1.00						
Pb	0.15	0.30	0.08	**−0.42**	−0.12	0.20	0.32	0.08	**−0.52**	1.00					
Co	−0.45	−0.35	**−0.72**	−0.45	−0.09	0.17	0.24	0.02	−0.04	0.24	1.00				
Ni	0.34	0.19	**0.76**	0.27	−0.14	0.09	−0.42	0.04	−0.18	−0.27	**−0.82**	1.00			
Zn	0.03	**−0.43**	**−0.42**	−0.09	−0.07	0.09	0.66	0.05	−0.31	0.10	0.21	−0.23	1.00		
Cr	0.27	0.38	**0.45**	**0.53**	−0.21	0.11	**−0.47**	0.04	−0.01	**−0.41**	**−0.59**	**0.65**	−0.27	1.00	
Al	0.33	0.25	**0.45**	−0.30	−0.16	0.22	0.10	0.17	−0.26	**0.51**	−0.10	0.14	−0.19	−0.33	1.00

M1 and M2 are not affected by Fe and Mn hydroxides. The good positive relationship between Ni and Cr in M1 and of Cu with Pb and Zn in M2 suggests that the source of the metal input might be similar or from anthropogenic sources. Significant correlations observed between organic matter (TOC, TP, and TN) and some of the metals indicate a significant role of organic matter in the process of trapping and incorporating the metals in the sediments.

Anthropogenic Factor (AF)

In order to differentiate between lithogenic and anthropogenic inputs of heavy metals, the anthropogenic factor of elements in both the cores was calculated. The results will help to indicate the extent of anthropogenic influence on metal deposition. AF was calculated according to Szefer et al. (1998), using the following formula:

$$AF = Cs/Cd \qquad (EQ2)$$

Where, Cs and Cd refer to the concentrations of the elements in the surface sediments and at depth in the sediment column.

According to Ruiz-Fernandez et al. (2001), if AF is >1 for a particular metal, it means contamination exists; otherwise, if AF is ≤ 1, there is no metal enrichment of anthropogenic origin. AF plots for the cores collected in Manori Creek are shown in Figures 3 and 4. Pb and Ni in M1 and Cu, Ni, and Zn in M2 show AF values >1 reflecting input by anthropogenic sources. Metal enrichment in this region can be attributed to both the direct discharges from point sources such as wastewater discharge and river carrying contaminants, influenced by the hydrological and sedimentation conditions in the creek. The Dahisar River, which drains the creek, is becoming highly polluted with the dumping of industrial effluents from industrial workshops and sewage from slums and storm water draining into it. Also, some part of the metals likely arise from non-point sources, for instance, leaching of soils, agricultural practises and atmospheric deposition.

Index of Geoaccumulation (Igeo)

Igeo, which compares present day contaminant concentrations with pre-civilization background values, was used to quantitatively estimate the metal pollution status of the sediments. It is

Table 2. *Pearsons correlation coefficients for sediment component, organic matter and selected elements in core M2 (p < 0.05, n = 21)*

	TOC	TP	TN	Sand	Silt	Clay	Cu	Fe	Mn	Pb	Co	Ni	Zn	Cr	Al
TOC	1.00														
TP	0.17	1.00													
TN	0.16	**0.56**	1.00												
Sand	0.32	−0.29	**−0.47**	1.00											
Silt	−0.02	−0.20	−0.08	0.19	1.00										
Clay	−0.04	0.25	0.16	−0.36	**−0.99**	1.00									
Cu	**0.52**	0.51	**0.49**	−0.09	−0.07	0.08	1.00								
Fe	−0.03	−0.42	0.03	−0.18	−0.22	0.24	0.26	1.00							
Mn	0.36	**0.46**	0.25	0.38	0.13	−0.19	0.12	**−0.59**	1.00						
Pb	0.14	0.31	**0.52**	−0.28	−0.17	0.22	**0.62**	**0.55**	−0.07	1.00					
Co	−0.18	0.20	−0.06	0.01	0.07	−0.06	0.08	0.09	0.00	0.11	1.00				
Ni	−0.02	**0.87**	0.33	−0.28	−0.15	0.19	0.31	**−0.55**	0.27	0.04	0.33	1.00			
Zn	0.22	**0.87**	**0.52**	**−0.45**	−0.17	0.24	0.66	−0.22	0.13	0.41	0.13	**0.82**	1.00		
Cr	0.18	−0.27	−0.22	−0.13	**−0.43**	0.43	−0.08	0.35	−0.21	−0.08	−0.04	−0.32	−0.21	1.00	
Al	−0.11	−0.01	0.34	**−0.56**	−0.03	0.13	0.31	**0.55**	−0.28	**0.53**	0.10	−0.08	0.19	0.27	1.00
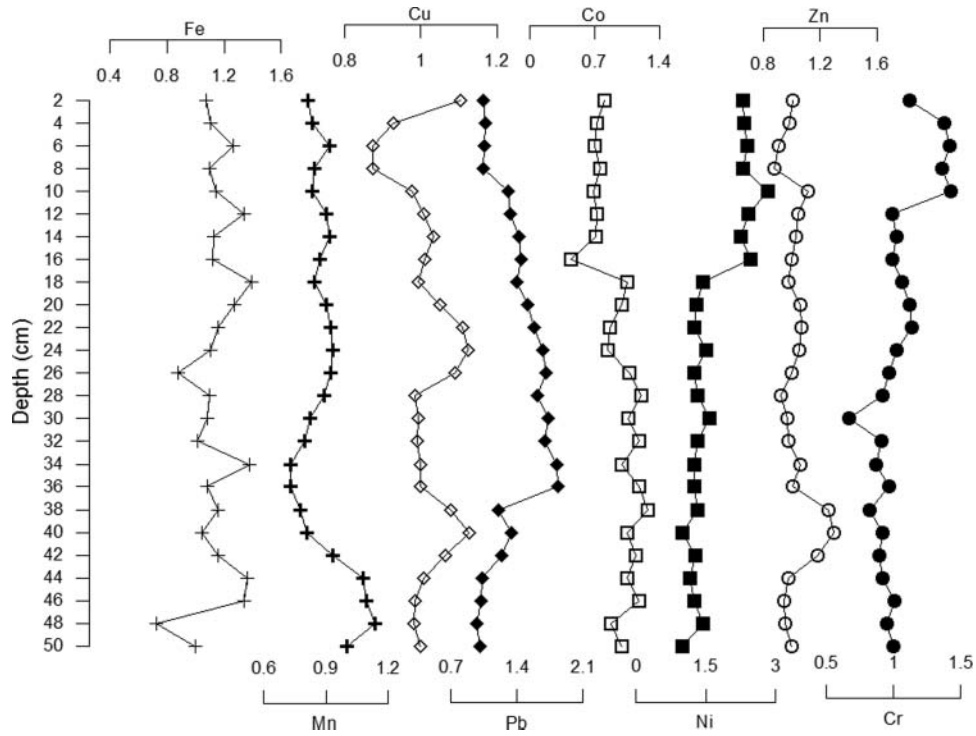
Figure 3. Downcore distribution of AF of selected metals Fe, Mn, Cu, Pb, Co, Ni, Zn, and Cr in core M1.

a semi-quantitative approach based on differences between current measurements and subtracted from "average global shale" measurement taken as background values (Muller, 1979). The Igeo is given by Equation (3)

$$Igeo = \log_2(Cn/1.5\ Bn) \qquad (EQ3)$$

where Cn = the measured concentration of the element "n" in the sediment fraction;

Bn = geochemical background of element "n", taken from literature (average global shale). The factor 1.5 is introduced to include the possible variations of the background values due to lithogenic variations.
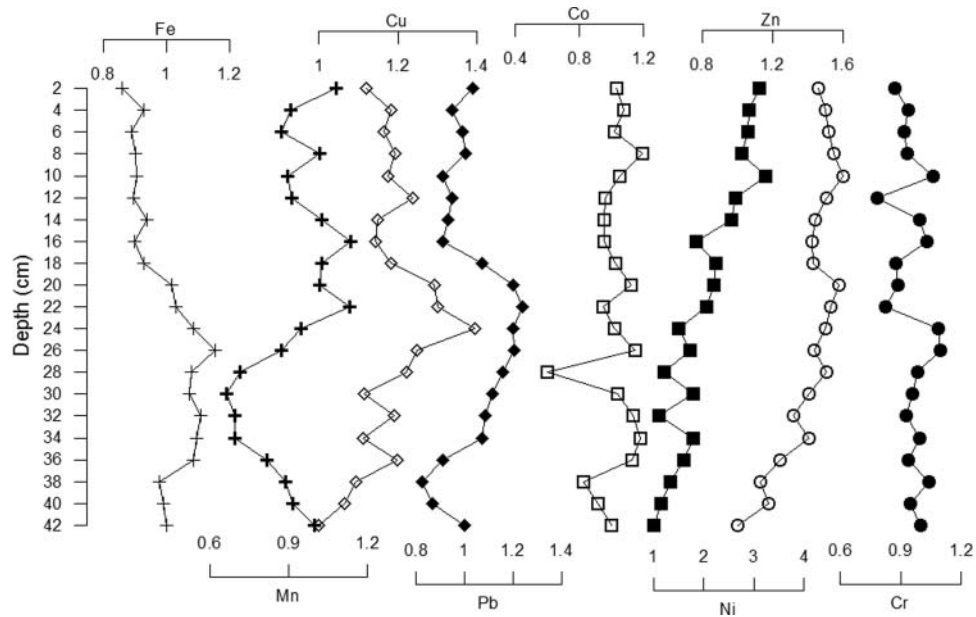

Figure 4. Downcore distribution of AF of selected metals Fe, Mn, Cu, Pb, Co, Ni, Zn, and Cr in core M2.
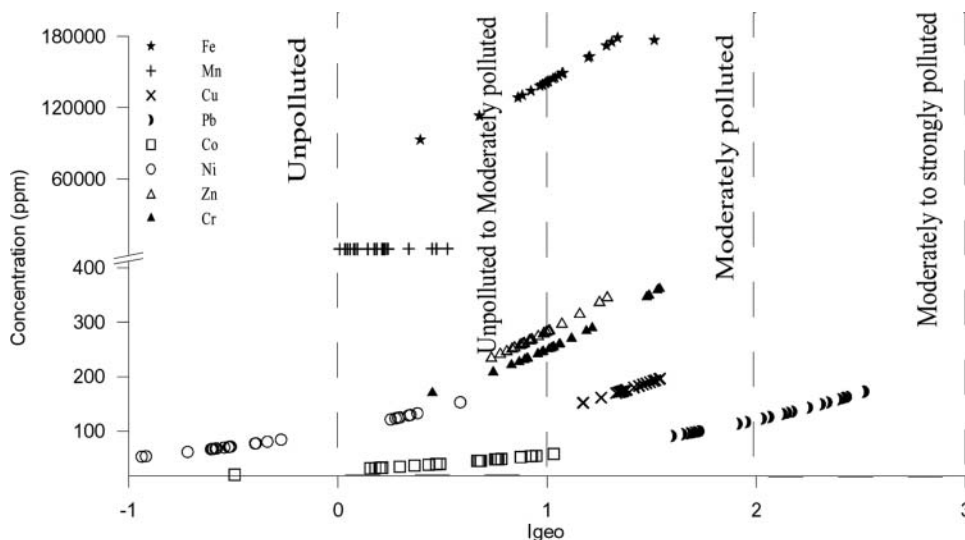
Figure 5. Distribution of concentration and Igeo values of selected metals Fe, Mn, Cu, Pb, Co, Ni, Zn, and Cr in core M1.

Table 3 gives the classification for metal pollution. Class 0 to class 6 represents increasing intensity of pollution i.e., from unpolluted to very strongly polluted. Figures 5 and 6 show the distribution of Igeo for selected metals in the study area. From the plots it is observed that Ni, Co, and Mn in M1 are all found to fall in class 1 whereas Fe, Cu, Zn, and Cr fall in class 2. Pb is found to fall in class 3. In M2, Ni falls in class 0, while Fe, Mn, Co, Zn, and Cr fall in class 1. Cu and Pb fall in class 2. The concentration of Pb is found to be significantly higher in both the cores and may be attributed to the deposition of Pb particulates released by vehicles and through atmospheric input of Pb from the use of leaded petrol by motor vehicles as well as fishing boats that operate in the creek. The sources of Cu include power plants, industrial areas, the use of copper sulphate as a fungicide in vineyards (Fernandez, 2000). The use of slurry as a fertiliser containing appreciable amounts of Cu, Zn, Fe, and Mn,

have also been observed to be an important Cu source (Lopez, 2002). Another possible source of Cu could be the anti-fouling products present in boat paints. Also the agricultural activities around the study area may have contributed to the observed high levels of Pb and Cu, since these metals can occur as impurities in fertilizers and in metal-based pesticides, compost and manure. Industrial activities may represent a primary source for Cr, Ni and Co, extensively used in the paint, chemical factories and textile works which are operational in the area. Additionally, Ni and Co might be linked to emissions from domestic heating systems (De Miguel et al., 1999).

Pollution Load Index (PLI)

Tomlinson's PLI (Tomlinson, 1980) in the sediment samples was calculated using the heavy metal data and metal concentrations
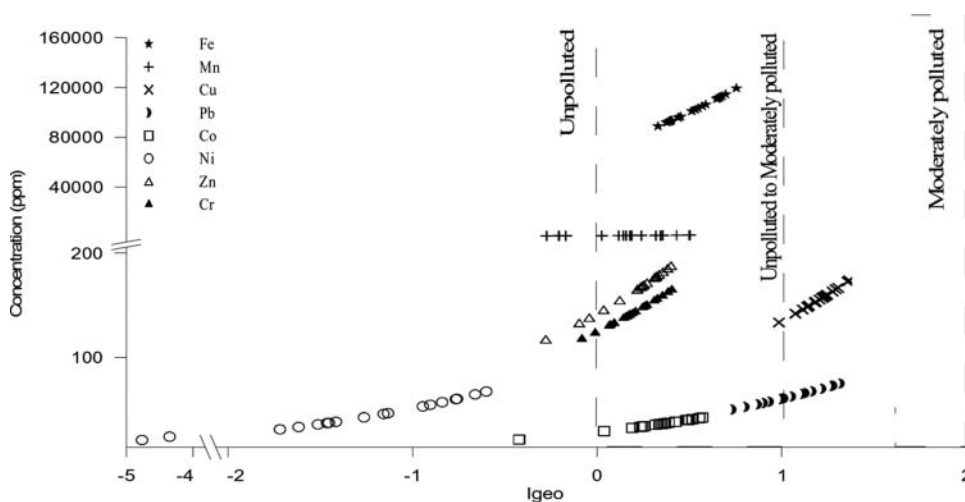

Figure 6. Distribution of concentration and Igeo values of selected metals Fe, Mn, Cu, Pb, Co, Ni, Zn, and Cr in core M2.

Table 3. *Geoaccumulation index proposed by Muller (1979)*

Pollution Intensity	Sediment Accumulation	Igeo class
Very strongly polluted	>5	6
Strongly to very strongly polluted	4–5	5
Strongly polluted	3–4	4
Moderately to strongly polluted	2–3	3
Moderately polluted	1–2	2
Unpolluted to moderately polluted	0–1	1
Practically unpolluted	<0	0

from world average shale (Turekian and Wedepohl, 1961) as the background value. PLI value gives the overall level of metal contents in a particular sample. The PLI is obtained as a contamination factor (Cf) of each metal with respect to the background value in the sediments (Angulo, 1996), by applying the following Equation (4)

$$\text{PLI} = \sqrt[n]{(Cf1 \times Cf2 \times \dots \times Cfn)} \qquad (EQ4)$$

where, Cf = Concentration of the metal in the sample (C_{metal}) /Concentration of metal in the background ($C_{\text{background}}$).

$$Cf = Ce/Cb, \qquad (EQ5)$$

where Ce = concentration of the element in sediment samples, and Cb = background value for the element taken from average global shale (Turekian and Wedepohl, 1961) The contamination

factor and pollution load index for cores M1 and M2 are given in Table 4 and Table 5. CF has been classified into four groups (Pekey et al., 2004; Hakanson, 1980). When CF <1, there is no metal enrichment by natural or anthropogenic inputs; $1 \le CF <3$ for a particular metal means that the sediment is moderately contaminated by the element; $3 \le CF <6$ means that there is considerable contamination; and if $CF \ge 6$, then there is very high contamination for that metal. CF values calculated in the present study indicate that the sediments of M1 are moderately contaminated by Mn, Co, Ni, and Zn; the elements Cu, Fe, and Cr are considerably contaminated whereas Pb shows very high contamination. In M2, Ni is not contaminated in the sediment; Fe, Mn, Co, Zn, and Cr are moderately contaminated while Pb and Cu are considerably contaminated in most of the sediment samples. The PLI represents the number of times by which the metal contents in the sediment exceeds the background concentrations. The PLI values are found to increase from the bottom to the surface of both cores and are found to be particularly high in the top 20 cm of both cores. In M1, PLI ranges from 2.47 (46–48 cm) to 2.96 (8–10 cm) and in M2 it varies from 1.61 (38–40 cm) to 2.00 (18–20 cm). In M1, the PLI values are observed to be much higher when compared to M2 supporting considerable enrichment of pollutants in the region. Based on PLI values, it can be stated that M1 being proximal to the potential source of contaminants, particularly the sewage effluents and also the sampling site placed near the creek head-end, must be flushed to a lesser extent resulting in higher contaminant buildup. The PLI values are found to be very low in all samples of M2 (PLI >2) indicating low pollution concern.

Table 4. *Depthwise values of Contamination Factor (CF), Pollution Load Index (PLI) and Contamination degree (Cd) in core M1*

Depth(cm)	CF-Fe	CF-Mn	CF-Cu	CF-Pb	CF-Co	CF-Ni	CF-Zn	CF-Cr	PLI	Cd
2	2.93	1.55	4.27	4.91	1.93	1.83	2.86	3.42	2.75	23.70
4	3.01	1.59	3.59	5.00	1.74	1.84	2.78	4.21	2.74	23.76
6	3.44	1.74	3.38	4.98	1.70	1.90	2.57	4.33	2.78	24.02
8	2.99	1.60	3.38	4.91	1.84	1.82	2.49	4.17	2.69	23.21
10	3.11	1.58	3.77	6.15	1.67	2.25	3.15	4.35	2.96	26.04
12	3.65	1.71	3.89	6.29	1.74	1.91	2.97	3.04	2.87	25.19
14	3.08	1.74	4.00	6.69	1.72	1.79	2.91	3.13	2.82	25.06
16	3.06	1.66	3.91	6.80	1.07	1.95	2.84	3.02	2.65	24.30
18	3.79	1.60	3.84	6.59	2.54	1.14	2.77	3.25	2.82	25.52
20	3.45	1.71	4.07	7.16	2.38	1.03	2.99	3.42	2.85	26.21
22	3.16	1.76	4.29	7.48	2.08	1.00	3.02	3.48	2.81	26.27
24	3.00	1.77	4.35	7.93	2.03	1.19	2.97	3.12	2.83	26.36
26	2.40	1.76	4.22	8.06	2.58	0.99	2.83	2.95	2.73	25.78
28	2.98	1.69	3.81	7.64	2.89	1.05	2.62	2.81	2.75	25.50
30	2.95	1.56	3.84	8.15	2.55	1.24	2.74	2.05	2.67	25.10
32	2.76	1.51	3.83	8.03	2.84	1.05	2.76	2.78	2.71	25.56
34	3.75	1.39	3.87	8.60	2.39	0.99	3.01	2.67	2.75	27.19
36	2.95	1.39	3.86	8.64	2.86	0.99	2.84	2.96	2.75	26.48
38	3.15	1.48	4.17	5.68	3.07	1.04	3.57	2.51	2.74	24.66
40	2.84	1.54	4.36	6.30	2.53	0.78	3.66	2.81	2.65	24.82
42	3.16	1.77	4.12	5.84	2.75	1.00	3.34	2.73	2.76	24.72
44	3.72	2.05	3.90	4.86	2.54	0.91	2.77	2.80	2.67	23.55
46	3.65	2.08	3.81	4.80	2.86	0.99	2.67	3.07	2.74	23.91
48	1.97	2.16	3.80	4.56	2.11	1.14	2.69	2.91	2.47	21.34
50	2.72	1.90	3.87	4.73	2.41	0.79	2.83	3.06	2.51	22.30

Table 5. *Depthwise values of Contamination Factor (CF), Pollution Load Index (PLI) and Contamination degree (Cd) in core M2*

Depth(cm)	CF-Fe	CF-Mn	CF-Cu	CF-Pb	CF-Co	CF-Ni	CF-Zn	CF-Cr	PLI	Cd
2	1.88	2.02	3.32	3.13	1.92	0.95	1.81	1.57	1.94	16.60
4	2.03	1.70	3.51	2.88	2.01	0.89	1.86	1.69	1.93	16.56
6	1.95	1.63	3.46	3.00	1.89	0.88	1.88	1.66	1.90	16.34
8	1.97	1.90	3.54	3.04	2.22	0.84	1.92	1.68	1.99	17.12
10	1.98	1.67	3.49	2.75	1.96	0.99	1.98	1.92	1.98	16.74
12	1.96	1.70	3.67	2.88	1.79	0.80	1.87	1.42	1.84	16.09
14	2.05	1.92	3.41	2.81	1.78	0.78	1.79	1.80	1.90	16.32
16	1.97	2.12	3.39	2.75	1.78	0.56	1.77	1.86	1.83	16.20
18	2.03	1.92	3.51	3.25	1.91	0.68	1.77	1.58	1.89	16.65
20	2.23	1.90	3.84	3.63	2.09	0.67	1.95	1.60	2.00	17.91
22	2.25	2.12	3.86	3.75	1.76	0.63	1.89	1.49	1.96	17.75
24	2.37	1.77	4.14	3.63	1.89	0.46	1.86	1.96	1.94	18.08
26	2.53	1.63	3.71	3.65	2.14	0.53	1.78	1.98	1.96	17.94
28	2.36	1.33	3.63	3.50	1.12	0.37	1.87	1.78	1.65	15.96
30	2.35	1.24	3.31	3.38	1.93	0.54	1.74	1.73	1.79	16.23
32	2.43	1.30	3.53	3.29	2.12	0.31	1.63	1.67	1.68	16.28
34	2.40	1.30	3.30	3.25	2.20	0.55	1.74	1.79	1.83	16.52
36	2.38	1.53	3.56	2.75	2.11	0.49	1.54	1.70	1.77	16.04
38	2.14	1.66	3.24	2.50	1.54	0.40	1.40	1.88	1.62	14.47
40	2.17	1.71	3.16	2.63	1.71	0.35	1.46	1.71	1.61	14.61
42	2.19	1.87	2.97	3.03	1.87	0.34	1.24	1.81	1.64	15.01

Degree of Contamination

The assessment of the overall contamination of sediment was also attempted based on the degree of contamination (*Cd*). The sum of the contamination factors of all elements examined represents the contamination degree (Cd) of the environment.

$$Cd = \sum_{i=1}^{m} Cf^i \qquad (EQ6)$$

where, Cf = the contamination factor and m = multiple metals. Four classes (Hakanson, 1980; Aksu et al., 1998) have been used to define the degree of contamination of the creek in the present study. $Cd < 7$ means low degree of contamination; $7 \leq Cd < 14$ means moderate degree of contamination; $14 \leq Cd < 28$ means considerable degree of contamination while $Cd \geq 28$ means very high degree of contamination.

From Table 4 and Table 5, it is seen that both cores fall into the considerable degree of contamination class. However, M1 has higher Cd values than M2. Municipal and/or industrial wastewater discharges into coastal zones are the most important sources for contamination of water and sediment with heavy metals (Gonzalez and Brugmann, 1991). Therefore, Cd showed the overall contaminant status of the region. To further differentiate the pollutant category, the pollution sources of the creek was divided into two main groups: point and nonpoint sources. The main point sources are the discharges of wastewaters coming from commercial, industrial and agricultural activities and the residential area. Non-point sources would be the drainage waters coming from runoff, the ground water including leachates and the discharge of wastewaters from unknown sources. In the present case, largely the point source is responsible for the level of pollution.

Sediment Quality Guidelines

If the concentration of metals incorporated in sediments exceeds threshold values, a direct risk to detrital and deposit-feeding benthic organisms can occur, which may represent a long-term contamination source to higher trophic levels (Mendil and Uluözlü, 2007). Therefore, ecotoxicological effects of heavy metal contaminations in sediments was determined using sediment quality guidelines (SQGs) defined by McDonald et al. (2000), developed for marine and estuarine ecosystem (Bakan and Ozkoc, 2007). SQG values, referred to as the *threshold effect concentration (TEC)* and the *probable effect concentration (PEC)*, provide a reliable basis for assessing sediment quality conditions in aquatic ecosystems. TEC defines values below which harmful effects are unlikely to be observed, while PEC defines values above which harmful effects are likely to be observed. The potential ecological risk to the aquatic system by heavy metals in sediments was also assessed. In relation to this, the effects range-low (ERL) and effects range-median (ERM) concentrations were considered. The ERL represents chemical concentrations below which adverse biological effects are rarely observed, while the ERM represents concentrations above which effects are more frequently observed (Long et al., 1995; 1997).

From Table 6, it is observed that near the mouth of the creek, M2, most of the mean values of the studied heavy metals (Ni, Cr, Cu, Pb, and Zn) are found to be greater than the TEL values but lower than the PEL values except for Cu and Cr. In the case of M1 (inner creek end), almost all the elements in the core exceed the TEL values. The metal concentration of Pb and Zn are lower than the PEL values while Cu, Ni and Cr shows values higher than PEL. At both the sites, the concentrations of Cu, Pb, Ni, Zn and Cr are found to be above the ERL values, while the mean values are lower than the ERM values for all the elements except for Ni, which shows values higher than

Table 6. *Ecotoxicological effects according to SQGs for Manori creek*

Element	M1	M2	TEL[a]	PEL[a]	ERL[b]	ERM[b]
Fe	14.67	10.26	—	—	—	—
Mn	1013	1026	—	—	—	—
Cu	176	157	31.6	149	34	270
Pb	128	62	35.8	128	46.7	218
Co	43	36	—	—	—	—
Ni	89	42	22.7	48.6	20.9	51.6
Zn	276	166	121	459	150	410
Cr	262	143	31.6	111	81	370

[a]MacDonald et al. (2000); [b]Long et al. (1995; 1997); except Fe (%), all metals are in ppm.

ERM. There are no guideline values available for Fe, Co and Mn. The observations from SQG guidelines indicate that the creek sediments are contaminated with heavy metals and may contribute to sediment toxicity in the aquatic ecosystem of the Manori Creek. The present study is part of a long-term research project being carried out along Mumbai coast. Further studies involving Metal speciation, which involves the extent to which the metals are present in the different sediment phases (carbonates, oxides, hydroxides, sulphides, organometallic compounds, etc), will give a better picture of the the potential pollution effects of metal-bearing sediments to biota (e.g., bioavailability and toxicity) and hence will be considered in the future.

Conclusions

The spatio-temporal study carried out on the sediments of Manori Creek along Mumbai coast, indicated that the inner area of the creek show higher levels of most of the metal studied compared to the mouth of the creek. The possible reason for the elevated metal concentrations was sewage discharge and agricultural wastes in the vicinity of the study area. The various indices of pollution calculated showed the sediments of the creek as moderately polluted with respect to Pb and Cu and unpolluted to moderately polluted with the remaining elements. PLI indicated higher metal concentrations in recent years. Pb emissions from automobile exhausts and use of Cu as anti-fouling agents in boats and trawlers may have contributed significantly to the observed higher levels. SQG values showed most of the elements were above the threshold limit suggesting possible adverse impacts on the sediment dwelling fauna.

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