

Sediment Contamination Due to Toxic Heavy Metals in Mithi River of Mumbai

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Abstract The present study deals with quantification of accumulated toxic heavy metals in sediments of Mithi River of Mumbai. The study was performed at three different sampling locations along the flow of Mithi River for two years from 2009-12. The different heavy metals studied were Al, As, Cd, Cr, Hg, Ni, Pb, Sr and Mn. The results of our study indicate that the concentration level of these toxic heavy metals for the two assessment years increases by the factor of 1.2-5.8 µg/g. The result is a clear indication of day by day increasing pollution level of the Mithi River, which is creating negative environmental impact on biological life of the river. The results emphasises the need of regular scientific monitoring of different pollutants adversely affecting the environment and to reframe the pollution control strategies already in existence.

Keywords Sediments, Toxic Heavy Metals, Quantification Study, Environmental Impact, Biological Life, Mithi River, Mumbai, India

1. Introduction

Among the inorganic contaminants of the river water, heavy metals are getting importance for their non-degradable nature and often accumulate through tropic level causing deleterious biological effect. These toxic heavy metals are creating more serious environmental problem owing to their long biological half lives. It is also difficult to remove them completely from the environment once they enter into it. Rivers are a dominant pathway for transport of these heavy metals[1, 2] which have become significant pollutants of many riverine systems. Anthropogenic activities like mining, ultimate disposal of treated/untreated waste effluents containing toxic metals as well as metal chelates[3] from different industries and also the indiscriminate use of heavy metal containing fertilizers and pesticides in agriculture resulted in deterioration of water quality rendering serious environmental problems posing threat on human beings[4] and sustaining aquatic biodiversity[5,6]. Though some of the metals like Cu, Fe, Mn, Ni and Zn are essential as micro nutrients for life processes in plants and microorganisms, while many other metals like Cd, Cr and Pb have unknown physiological activity, but they are proved detrimental beyond a certain limit[7], which is very much narrow for some elements like Cd (0.01 mg/L), Pb (0.10 mg/L) and Cu (0.050 mg/L). The deadlier diseases like edema of eyelids, tumor, congestion of nasal mucous membranes and pharynx,

stiffness of the head and gastrointestinal, muscular, reproductive, neurological and genetic malfunctions caused by some of these heavy metals have been documented[8,9].

The behavior of metals in natural waters is a function of the substrate sediment composition, the suspended sediment composition, and the water chemistry. During their transport, the heavy metals undergo numerous changes in their speciation due to dissolution, precipitation, sorption and complexation phenomena[10, 11] which affect their behaviour and bioavailability[12, 13]. The overall behavior of heavy metals in an aquatic environment is strongly influenced by the associations of metals with various geochemical phases in sediments[14]. Due to their particle reactivity, metals tend to accumulate in sediments, and, as a result, may persist in the environment long after their primary source has been removed. These toxic metals are not necessarily fixed by the sediments permanently, but may be recycled via biological and chemical agents both within the sedimentary compartment as well as in the water column. Behaviour of these metals in the coastal marine sediments is largely related to their capacity for complexation with organic matter in truly dissolved, colloidal, macro particulate phases. These metals entering the ecosystem may lead to geoaccumulation, bioaccumulation, biomagnification and may have possibilities for environmental transformation into more toxic form. These toxic heavy metals entering in aquatic environment are adsorbed onto particulate matter, although they can form free metal ions and soluble complexes that are available for uptake by biological organisms[15] or get deposited in estuarine sediments[16]. Once deposited, binding by sulphides and/or iron hydroxides immobilizes trace metals until a change in redox or pH

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occurs [17, 18]. In hydrosphere, toxic metal concentrations are typically orders of magnitude greater in the sediments as compared to those in overlying waters. Thus, superficial sediments, particularly the fine fraction, accumulate toxic heavy metals and provide a means for evaluating the long term accumulation of these metal contaminants [17, 19]. The capacity of sediments to concentrate trace levels of most of the metals also make them useful indicators for monitoring purposes and for detecting sources of pollution in the aquatic system. These heavy metals are sensitive indicators for monitoring changes in the water environment. Also the experimental data obtained based on analysis of sediment cores helps to provide a historical record of the heavy metal burdens. The monitoring these toxic heavy metals are important for safety assessment of the environment and human health in particular.

The problem of environmental pollution due to heavy metals has begun to cause concern now in most of the major metropolitan cities in Maharashtra state and Mumbai is not an exception to it. The day by day increasing tremendous pollution of water bodies [20-30] has prompted us to carry the systematic and detail study of pollution due to toxic heavy metals in sediments at different sampling stations along the flow of Mithi River which is considered as one of the heavily polluted river of Mumbai.

2. Materials and Methods

2.1. Area of Study

The water sampling was done from three different sampling stations along the flow of Mithi River namely Airport (**L1**), CST Kalina (**L2**) and BKC Taximen's Colony (**L3**). Airport site near Jari Mari area is thickly populated and has many small scale industries including scrap dealers. Previous short term study conducted by Maharashtra Pollution Control Board shows the presence of cyanide, consistent high COD, oil and grease found at this station indicating some chemical activity in that area [21]. Unauthorized encroachments by illegal industrial units, scrap dealers and oil mixing business at CST road near Kalina, have further resulted in discharge of solid waste, organic waste, industrial waste, heavy metals, oils and tar in the river. This sampling point is surrounded by many small scale industries including recyclers, barrel cleaners, workshops and other units. This area has thick density of population. Illegal activities like washing of oily drums have resulted in discharge of unauthorized hazardous waste which is carried out along the bank of this river. Development of Bandra-Kurla Complex has resulted in diversion and unnatural turn along the Mithi River at few places thereby affecting natural flow of the river and seriously affected the drainage. This part of the river is a dumping ground for garbage and it is reflected in higher values of suspended solids. The organic waste, sludge and garbage dumping has reduced the carrying capacity of the Mithi River. The solid

wastes which is discharged in to the Mithi river from the surrounding illegal industries and the slums has resulted in sever water logging during 26/7 deluge in Mumbai. The map showing flow of Mithi River is shown in Figure 1.

2.2. Climatic Conditions

The area is located along western Arabian cost of India from 18 deg. 53' north to 19 deg. 16' north latitude and from 72 deg. east to 72 deg. 59' longitude. The area experiences tropical savanna climate. It receives heavy south west monsoon rainfall, measuring 2166 mm on an average every year. The temperature ranges from 16 deg. centigrade to 39 deg. centigrade with marginal changes between summer and winter months. Whereas relative humidity ranges between 54.5 to 85.5%.

2.3. Requirements

The chemicals and reagent were used for analysis were of Analytical Reagent (AR) grade. The procedure for calculating the different parameters were conducted in the laboratory. The laboratory apparatus were soaked in nitric acid before the analysis. After acid soaked, it is rinsed thoroughly with tap water and de-ionised distilled water to ensure complete removal of any traces of cleaning reagents. Finally, it is dried and stored in a clean place. The pipettes and burette were rinsed with solution before final use.

2.4. Sediment Sampling, Preparation and Analyses

The sediment samples were collected randomly four times in a month in morning, afternoon and evening session from three different sampling stations along the flow of Mithi River (Figure 1). The samples were collected and subsequently analysed for a span of two years starting from October 2009 to September 2011. The sampling was done in three shifts i.e. morning shift between 07:00 a.m. to 09:00 a.m., afternoon shift between 02:00 p.m. to 04:00 p.m. and evening shift between 07:00 p.m. to 09:00 p.m. Sediment samples were collected by hand-pushing plastic core tubes (7 cm diameter) as far as possible into the sediment. The sediment cores retrieved in the field were sliced on arrival at the lab at 1-cm depth intervals for the first 15 cm, 2-cm depth intervals from 15–25 cm, and then every 5 cm for the deeper sections of the cores. The sediments were kept cool in icebox during the transportation to the laboratory [31, 32]. They were then ground manually to a fine powder in an alumina mortar; passed through a 2-mm mesh screen and stored / preserved in polyethylene bags for further analysis. Well-mixed samples of 2 g each was taken in 250 mL glass beakers and digested with 8 mL of aqua regia on a sand bath for 2 hr. After evaporation to near dryness, the samples were dissolved with 10 mL of 2% nitric acid and filtered through Whatman's No.1 filter paper. The samples were subjected to nitric acid digestion using the microwave-assisted technique, setting pressure at 30 bar and power at 700 W [33, 34]. About 400 mL of the sample was transformed into clean glass separating funnel in which 10 mL of 2% ammonium

pyrrolidine dithiocarbamate, 4 mL of 0.5 M HCl and 10 mL of methyl isobutyl ketone (MIBK) are added[35]. The solution in separating funnel was shaken vigorously for 2 min and was left undisturbed for the phases to separate. The MIBK extract containing the desired metals was then diluted to give final volumes depending on the suspected level of the metals[36]. The sample solution was then aspirated into air acetylene flame in an atomic absorption spectrophotometer.

2.5. Heavy Metal Analysis By AAS Technique

The analysis for the majority of the trace metals like aluminum (Al), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), strontium (Sr) and manganese (Mn) was done by Perkin Elmer ASS-280 Flame Atomic Absorption Spectrophotometer. Arsenic (As) was determined by hydride generation coupled with an atomic fluorescence detector, while mercury (Hg) was analysed with a cold-vapour atomic adsorption spectrophotometer. An atomizer with an air/acetylene burner was used for determining all the elements investigated. All instrumental settings were those recommended in the manufacturer's manual book. To analyse the solutions extracted, an aliquot 100 μ L of the solution was introduced to nebulizer of flame AAS. The detection limits of Al, As, Cd, Cr, Hg, Ni, Pb, Sr and Mn 15, 20, 2, 20, 5, 25, 45, 10 and 5 μ g/g respectively. The calibration curves were prepared separately for all the metals by running different concentrations of standard solutions. A reagent blank was taken through the method, analyzed and subtracted from the samples to correct for reagent impurities and other sources of errors from the environment. Average values of three replicates were taken for each determination.

2.6. Quality Control/Assurance

Sediment samples were collected with plastic-made implements to avoid contamination. Samples were kept in polythene bags that were free from heavy metals and organics and well covered while transporting from field to the laboratory to avoid contamination from the environment. Reagent blanks were used in all analyses to check reagent impurities and other environmental contaminations during analyses. Analytical grade reagents were used for all analyses. All glassware used were soaked in appropriate dilute acids overnight and washed with teepol and rinsed with deionised water before use. Tools and work surfaces were carefully cleaned for each sample during grinding to avoid cross contamination. Replicate samples were analysed to check precision of the analytical method and instrument. To validate the analytical procedures used, the spike recovery test was conducted on some sediment samples for Al, As, Cd, Cr, Ni, Pb, Sr, Mn and Hg.

3. Results and Discussion

Toxic heavy metals are released into the environment from metal smelting and refining industries, scrap metal, plastic and rubber industries, various consumer products and

from burning of waste containing these elements. On release to the air, the elements travel for large distances and are deposited onto the soil, vegetation and water depending on their density. Discharge of treated/partially treated or untreated domestic and agricultural wastes also leads to the pollution of water bodies due to the heavy metals[37]. These metals entering in aquatic environment are adsorbed onto particulate matter, although they can form free metal ions and soluble complexes that are available for uptake by biological organisms. The metals associated with particulate material are also available for biological uptake, and are deposited in estuarine sediments[38]. Once deposited, binding by sulfides and/or iron hydroxides immobilises trace metals until a change in redox or pH occurs. Thus, surficial sediments, particularly the fine fraction, accumulate trace metals and provide a means for evaluating the long term accumulation of heavy metal contaminants[39]. These heavy metals which are accumulated in sediments are not degraded and persist in the environment for many years poisoning humans through inhalation, ingestion and skin absorption. Acute exposure leads to nausea, anorexia, vomiting, gastrointestinal abnormalities and dermatitis.

The experimental data on concentration (μ g/g) of toxic heavy metals like Al, As, Cd, Cr, Hg, Ni, Pb, Sr and Mn in the sediment samples collected along sampling stations L1, L2 and L3 of Mithi River is presented in Table 1. The trend in average concentration of these metals at different sampling stations for the assessment years 2009-10 and 2010-11 is graphically represented in Figures 2-4.

From the results it was observed that aluminum (Al) concentration at different sampling stations lies in the range of 22-243, 52-729, and 32-851 μ g/g at the respective sampling stations. The biyearly average Al concentration was found to be 77, 212 and 250 μ g/g respectively at different sampling stations (Table 1). It was also observed that the average Al concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 3.03 at L1 to 3.43 at L2 sampling stations (Figures 2-5). It is important here to note that aluminum toxicity is an important growth-limiting factor for plants in many acid soils, particularly in pH of 5.0 or below[40]. Aluminum toxicity in plants is often clearly identifiable through morphological and physiological symptoms. Differential tolerances to Al toxicity almost certainly involves differences in the structure and function of roots. Aluminum interferes with cell division in roots, decreases root respiration and uptake and use of water and nutrients, particularly calcium and phosphorous and metabolic pathway[41-43].

Levels of arsenic (As) are higher in the aquatic environment than in most areas as it is fairly water-soluble and may be washed out of arsenic bearing rocks. Recently, the anthropogenic activities such as treatment of agricultural land with arsenical pesticides, treating of wood using chromated copper arsenate, burning of coal in thermal plants power stations and the operations of gold-mining have increased the environmental pervasiveness of As and its rate

of discharge into freshwater habitat. Arsenic can also interfere with the fish immune system by suppressing antibody production[44] as well as by lowering macrophage activity and maturation[45]. Several studies are reporting *As* induced liver fibrosis, hepatocellular damage, inflammation, focal necrosis in addition to hepatocellular carcinoma[46]. In the present investigation it was observed that *As* concentration at L1, L2 and L3 sampling stations lies in the range of 26-450, 73-1530 and 56-1755 $\mu\text{g/g}$ respectively. The biyearly average *As* concentration was found to be 162, 509 and 585 $\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *As* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 3.98 at L1 to 4.25 at L2 sampling stations (Figures 2-5).

Although emissions of cadmium (*Cd*) in the environment have markedly declined in most industrialized countries, *Cd* remains a source of concern for industrial workers and for populations living in polluted areas, especially in less developed countries[47]. *Cd* dispersed in the environment can persist in soils and sediments for decades[48]. When taken up by plants, *Cd* concentrates along the food chain and ultimately accumulates in the body of people eating contaminated foods[48]. By far, the most salient toxicological property of *Cd* is its exceptionally long half-life in the human body. Once absorbed, *Cd* irreversibly accumulates in the human body, in particularly in kidneys and other vital organs such the lungs or the liver

[49]. In addition to its extraordinary cumulative properties, *Cd* is also a highly toxic metal that can disrupt a number of biological systems, usually at doses that are much lower than most toxic metals[50]. In the present investigation it

was observed that *Cd* concentration at L1, L2 and L3 sampling stations lies in the range of 12-398, 16-440 and 5-890 $\mu\text{g/g}$ respectively. The biyearly average *Cd* concentration was found to be 157, 140 and 308 $\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *Cd* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 5.04 at L1 to 5.78 at L3 sampling stations (Figures 2-5).

Chromium (*Cr*) is one of the most common skin sensitizers and often causes skin sensitizing effect in the general public. A possible source of chromium exposure is waste dumps for chromate-producing plants causing local air or water pollution. Penetration of the skin will cause painless erosive ulceration ("chrome holes") with delayed healing. These commonly occur on the fingers, knuckles, and forearms. The characteristic chrome sore begins as a papule, forming an ulcer with raised hard edges. Ulcers can penetrate deep into soft tissue or become the sites of secondary infection, but are not known to lead to malignancy[51, 52]. Besides the lungs and intestinal tract, the liver and kidney are often target organs for chromate toxicity[53]. In natural waters, exposure to *Cr* has demonstrated cumulative deleterious effects on fishes as a function of time[54, 55]. In the present investigation it was observed that *Cr*

concentration at L1, L2 and L3 sampling stations lies in the range of 92-932, 25-1656 and 63-1822 $\mu\text{g/g}$ respectively. The biyearly average *Cr* concentration was found to be 348, 491 and 593 $\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *Cr* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 2.10 at L3 to 2.50 at L1 and L2 sampling stations (Figures 2-5).

Mercury (*Hg*) poisoning has become a problem of current interest as a result of environmental pollution on a global scale. Mercury is a strong phytotoxic as well as genotoxic metal. High concentration of mercury, which could pose an ecological hazard, leading to contamination of plants[56, 57], aquatic resources and bioaccumulation in the food chain[58]. Although elemental mercury is relatively innocuous and non-toxic, it can be converted to organomercurials, which are particularly toxic and are retained in the cells of plants and living organisms. Reports by Tanaka[59] and Goldstone et al.[60] have dwelt on the natural alkylation of total mercury in waste water and water bodies. Recent studies have also reported that the inorganic mercury is transformed into methylmercury through microbial activity, which is the most toxic and most bioavailable form of mercury for living organisms[61]. Bodaly et al.[62] have reported that treated sewage water discharged into rivers and similar water bodies could result in an appreciable increase in the buildup of alkyl mercury. In the present investigation it was observed that *Hg* concentration at L1, L2 and L3 sampling stations lies in the range of 32-389, 20-238 and 13-97 $\mu\text{g/g}$ respectively. The biyearly average *Hg* concentration was found to be 189, 70 and 56 $\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *Hg* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 1.20 at L3 to 2.71 at L2 sampling stations (Figures 2-5).

Nickel(*Ni*) and nickel compounds have many industrial and commercial uses, and the progress of industrialization has led to increased emission of pollutants into ecosystems. Nickel is easily accumulated in the biota, particularly in the phytoplankton or other aquatic plants, which are sensitive bioindicators of water pollution. It can be deposited in the sediment by such processes as precipitation, complexation and adsorption on clay particles and via uptake by biota[63, 64]. Levels of precipitation of *Ni* of 0.9 $\text{mg/m}^2/\text{year}$ over long periods were found to be dangerous for biological systems of fresh water catchments[65]. In rivers, nickel is transported mainly as a precipitated coating on particles and in association with organic matter. Recent studies have suggested an increase in cancer in nickel refinery areas where exposure to water-soluble nickel salts occurs[66]. Nickel has been shown to be immunotoxic, altering the activity of all specific types involved in the immunological response, resulting in contact dermatitis or asthma. Human exposure to highly nickel-polluted environments has the potential to produce a variety of pathological effects. Among them are skin allergies, lung fibrosis, cancer of the

respiratory tract and iatrogenic nickel poisoning[67]. While no reproductive effects have been associated with nickel exposure to humans, several studies on laboratory animals have demonstrated fetotoxicity[68]. In the present investigation it was observed that *Ni* concentration at L1, L2 and L3 sampling stations lies in the range of 65-2157, 36-384 and 66-2427 $\mu\text{g/g}$ respectively. The biyearly average *Ni* concentration was found to be 1087, 205 and 1289 $\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *Ni* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 1.50 at L3 to 1.70 at L1 and L2 sampling stations (Figures 2-5).

Lead (*Pb*) inhibits plant growth, reduces photosynthesis, and reduces mitosis and water absorption. Lead concentrations in aquatic (and terrestrial) vertebrates tend to increase with increasing age of the organism, and to localize in hard tissues such as bone and teeth. Tetramethyl lead reportedly was produced from biological and chemical methylation of several inorganic and organic *Pb* compounds in the aquatic environment, and has been detected at low concentrations in marine mussels, lobsters, and bony fishes.

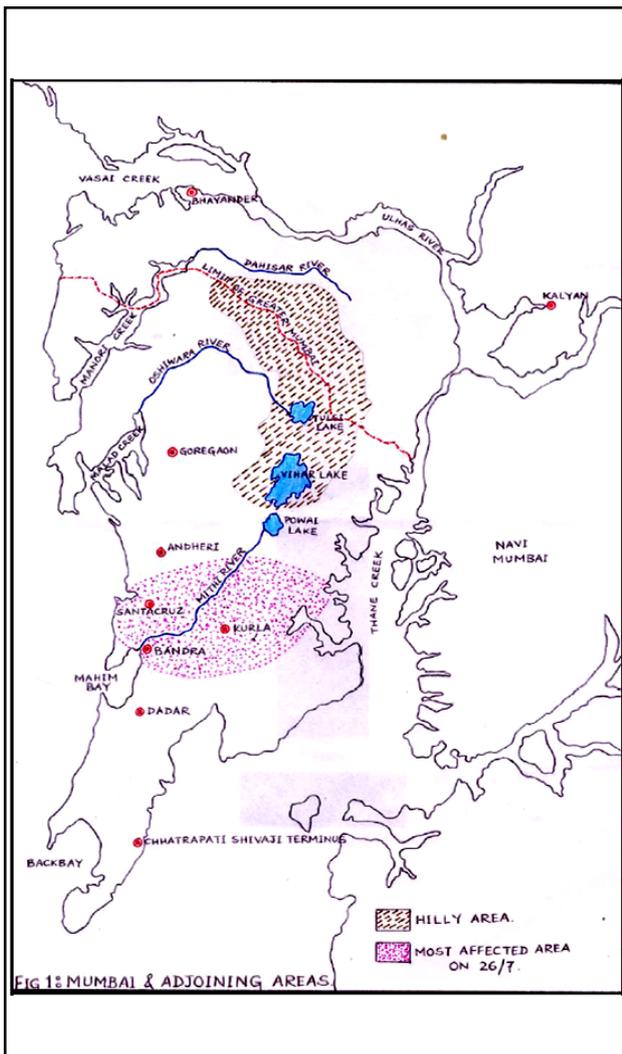


Figure 1. Map showing flow of Mithi River in Mumbai

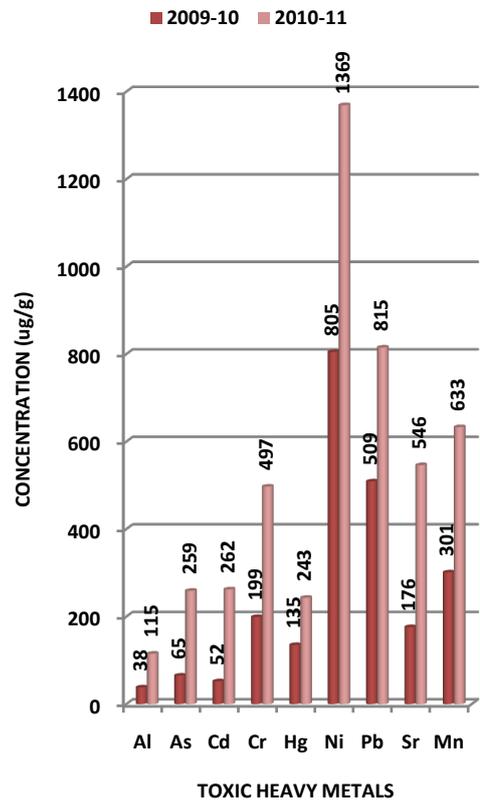


Figure 2. Variation in average concentration values of different toxic heavy metals in sediment samples collected at L-1 sampling station of Mithi River during the assessment year 2009-10 and 2010-11

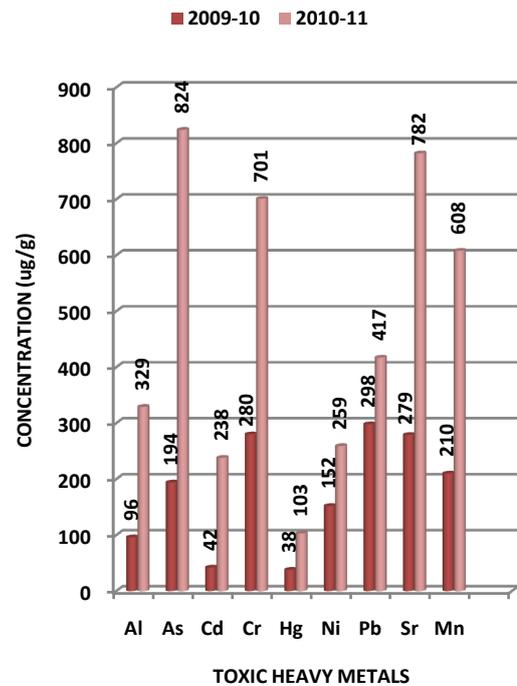


Figure 3. Variation in average concentration values of different toxic heavy metals in sediment samples collected at L-2 sampling station of Mithi River during the assessment year 2009-10 and 2010-11

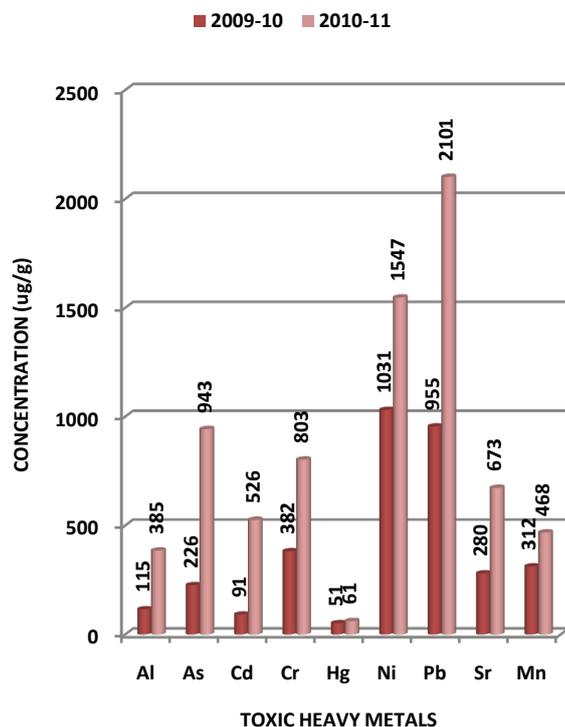


Figure 4. Variation in average concentration values of different toxic heavy metals in sediment samples collected at L-3 sampling station of Mithi River during the assessment year 2009-10 and 2010-11

Table 1. Heavy Metal Content in Sediment Samples Collected at different Sampling Stations along Mithi River of Mumbai (values in µg/g dry weight)

Heavy Metals	Al			As			Cd			Cr		
	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
Sampling Stations												
Month-Year												
October-09	26	65	78	76	229	267	63	42	125.2	114	341	446
November	23	58	69	81	242	283	71	47	142.4	123	370	484
December	33	83	100	75	225	263	59	40	118.8	110	331	434
January-10	30	75	90	69	206	241	54	36	107.2	92	303	419
February	41	103	123	67	200	233	57	38	114	119	358	468
March	49	122	146	70	209	243	60	40	120.4	133	400	523
April	53	133	159	77	231	270	76	51	151.6	161	482	632
May	81	203	243	113	338	394	80	53	159.2	221	662	867
June	45	113	136	55	164	192	55	77	26	302	25	63
July	34	85	102	41	123	144	27	37	12	339	28	73
August	24	60	72	28	85	99	12	16	5	373	31	88
September	22	54	65	26	79	92	17	24	8	300	33	90
October	78	234	273	305	1068	1190	313	261	783	284	852	937
November	69	207	242	323	1131	1260	356	297	890	308	924	1016
December	100	300	350	300	1050	1170	297	248	743	276	828	911
January-11	90	233	320	275	921	928	268	103	615	229	758	880
February	123	369	431	266	904	1037	285	219	627	298	894	983
March	146	438	511	278	945	1084	301	232	662	333	999	1099
April	159	477	557	308	1047	1201	379	292	834	402	1206	1327
May	243	729	851	450	1530	1755	398	306	876	552	1656	1822
June	136	408	476	219	745	1056	275	440	138	756	63	132
July	102	306	357	164	357	498	133	213	67	848	71	153
August	72	52	32	113	73	56	58	110	32	932	78	185
September	65	190	228	105	115	77	86	138	44	750	83	190
AVERAGE	77	212	250	162	509	585	157	140	308	348	491	593
Range	22-243	52-729	32-851	26-450	73-1530	56-1755	12-398	16-440	5-890	92-932	25-1656	63-1822
Median	132	391	441	238	802	906	205	228	448	512	841	942

Table 1. Heavy Metal Content in Sediment Samples Collected at different Sampling Stations along Mithi River of Mumbai (values in $\mu\text{g/g}$ dry weight) (continue)

Heavy Metals	Hg			Ni			Pb			Sr			Mn		
Sampling Stations	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
Month-Year															
October-09	160	38	60	1269	221	1320	617	454	1359	256	384	314	369	232	353
November	141	33	53	1167	208	1345	557	419	1301	244	351	362	424	268	389
December	159	37	60	1103	225	1324	499	331	1372	235	415	380	440	277	367
January-10	167	42	52	1214	226	1407	463	233	1409	222	411	408	459	309	413
February	178	42	67	1125	194	1517	531	256	1362	229	365	351	330	293	329
March	198	47	74	1089	161	1546	564	289	1156	211	344	371	352	287	385
April	193	45	73	846	152	1618	584	319	957	222	353	385	423	312	432
May	216	51	81	928	178	1523	613	352	1038	227	360	406	434	330	466
June	85	38	33	445	104	419	471	270	712	160	223	217	201	124	354
July	54	29	24	270	70	164	426	225	396	65	83	82	124	49	116
August	32	31	18	65	36	66	411	201	108	18	20	30	34	10	65
September	36	20	12	138	51	125	374	221	290	25	42	57	24	24	75
October	288	64	72	2157	376	1980	987	636	2989	793	1076	753	774	674	529
November	253	56	63	1984	353	2018	891	587	2863	756	982	869	891	776	583
December	286	64	72	1875	382	1986	798	463	3018	729	1163	912	925	803	551
January-11	301	71	62	2064	384	2110	741	326	3100	688	1150	980	963	895	620
February	320	71	80	1913	329	2275	850	359	2997	710	1021	843	694	850	493
March	356	79	89	1852	273	2319	903	405	2543	653	964	891	739	833	578
April	348	77	87	1439	258	2427	934	446	2106	687	989	923	889	905	648
May	389	86	97	1578	303	2285	980	493	2284	705	1007	975	912	956	699
June	153	238	40	756	177	629	753	378	1567	496	623	521	423	359	531
July	98	175	29	459	119	246	681	315	871	203	231	197	261	143	174
August	57	130	22	111	62	99	658	282	238	55	55	72	72	30	98
September	65	119	15	234	86	187	599	310	639	76	118	136	50	69	113
AVERAGE	189	70	56	1087	205	1289	662	357	1528	361	530	476	467	409	390
Range	32-389	20-238	13-97	65-2157	36-384	66-2427	374-987	201-636	108-3100	18-793	20-11982	30-9912	24-9925	10-983	65-699
Median	210	129	55	1111	210	1247	681	419	1604	405	591	505	493	483	382

High *Pb* concentration caused adverse physiological and reproductive effects in some species of birds and mammals[69]. Lead adversely affects survival, growth, reproduction, development, and metabolism of most species under controlled conditions, but its effects are substantially modified by numerous physical, chemical, and biological variables. Inorganic *Pb* in the environment can be biologically methylated to produce alkyl lead compounds.

Some microorganisms in lake sediments transform certain inorganic and organic *Pb* compounds into the more toxic tetramethyl lead, but the pathways are not well understood.

In general, organolead compounds are more toxic than inorganic *Pb* compounds, food chain biomagnifications of *Pb* is negligible, and the younger, immature organisms are most susceptible. Axonal degenerative changes, especially in

neuronal cell bodies, were recorded in *Pb*-poisoned freshwater snails (*Viviparous ater*), leading to altered protein synthesis[70]. Tetraethyl lead was about 10 times more effective than tetramethyl lead in reducing oxygen consumption by coastal marine bacteria, and was 1.5 to 4 times more toxic than tetramethyl lead to marine teleosts. Increasing waterborne concentrations of *Pb* over 10 $\mu\text{g/L}$ are expected to provide increasingly severe long-term effects on fish and fisheries. Lead seems to be tightly bound by most soils, and substantial amounts must accumulate before it affects the growth of higher plants. In the present investigation it was observed that *Pb* concentration at L1, L2 and L3 sampling stations lies in the range of 374-987, 201-636 and 108-3100 $\mu\text{g/g}$ respectively. The biyearly average *Pb* concentration was found to be 662, 357 and 1528

$\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *Pb* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 1.40 at L2 to 2.20 at L3 sampling stations (Figures 2-5).

Strontium (*Sr*) compounds that are water-insoluble can become water-soluble, as a result of chemical reactions. The water-soluble compounds are a greater threat to human health than the water-insoluble ones. Therefore, water-soluble forms of strontium have the opportunity to pollute aquatic environment. For children exceeded strontium uptake may be a health risk, because it can cause problems with bone growth. In the present investigation it was observed that *Sr* concentration at L1, L2 and L3 sampling stations lies in the range of 18-793, 20-1163 and 30-980 $\mu\text{g/g}$ respectively. The biyearly average *Sr* concentration was found to be 361, 530 and 476 $\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *Sr* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 2.40 at L3 to 3.10 at L1 sampling stations (Figures 2-5).

Manganese (*Mn*) is one out of three toxic essential trace elements, which means that it is not only necessary for humans to survive, but it is also toxic when too high concentrations are present in a human body. Excess manganese interferes with the absorption of dietary iron. Long-term exposure to excess levels may result in iron-deficiency anaemia. Increased manganese intake impairs the activity of copper metallo-enzymes. The presence of manganese in drinking water supplies may be objectionable for a number of reasons unrelated to health. At concentrations exceeding 0.15 mg/L, manganese stains plumbing fixtures and laundry and causes undesirable tastes in beverages[71]. Oxidation of manganese ions in solution results in precipitation of manganese oxides and incrustation problems. Even at concentrations of approximately 0.02 mg/L, manganese may form coatings on water distribution pipes that may slough off as black precipitates[72]. The growth of certain nuisance organisms is also supported by manganese[71, 73]. The presence of "manganese" bacteria, which concentrate manganese, may give rise to taste, odour and turbidity problems in the distributed water. Highly toxic concentrations of manganese in soils can cause swelling of cell walls, withering of leafs and brown spots on leaves. In the present investigation it was observed that *Mn* concentration at L1, L2 and L3 sampling stations lies in the range of 24-963, 10-956 and 65-699 $\mu\text{g/g}$ respectively. The biyearly average *Mn* concentration was found to be 467, 409 and 390 $\mu\text{g/g}$ respectively at different sampling stations (Table 1). It was also observed that the average *Mn* concentration for assessment year 2010-11 was higher than that obtained for the assessment year 2009-10 by a factor of 1.50 at L3 to 2.90 at L2 sampling stations (Figures 2-5).

4. Conclusions

Heavy metal pollution is an ever-increasing problem of our oceans, lakes and rivers. Incidence of heavy metal accumulation in fish, oysters, sediments and other components of aquatic ecosystems have been reported from all over the world. Environmental problems concerning coastal and aquatic bodies cannot be addressed in isolation. They are intricately interwoven with each other. The environments of land and sea are interdependent, linked by complex atmospheric, geological, physical, chemical and biological interactions. The human activities that affect and arise from this environment also depend on economic and social factors. The problem is beyond the limits of physical and institutional bodies and therefore, there is a need to set common objectives and implement compatible policies and programmes. Today, it is realised that solution to environmental problem can only be achieved through a comprehensive, systematic and sustained approach. During the past few years, attempts were made by various groups to develop strategies directed towards more integrated approach in coastal environments. The present data on heavy metal pollution in sediment samples collected along the Mithi River of Mumbai also points out to the need of regular monitoring of water resources and further improvement in the industrial wastewater treatment methods. What is more fundamentally lacking is a consistent, internationally recognised and data driven strategy to assess the quality of aquatic bodies and generation of international standards for evaluation of levels of contaminants.

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