

Sediment Heavy Metal Contaminants in Vasai Creek Of Mumbai: Pollution Impacts

Pravin U. Singare*, Manisha P. Trivedi, Ravindra M. Mishra

Department of Chemistry, Bhavan's College, Munshi Nagar, Andheri (West), Mumbai, 400058, India

Abstract In the present investigation, quantification study of different toxic heavy metals in the sediment samples of Vasai Creek of Mumbai was performed using Atomic Absorption Spectroscopy technique. The study is of importance because such assessment of heavy metals in sediments helps to understand long term pollution load in aquatic environment. Such study will also help to provide a means for evaluating the long term accumulation of heavy metal contaminants. The results of the study indicates that the concentration level of most of the toxic heavy metals like Al, As, Cd, Cr, Hg, Ni, Pb, Sr and Mn for the assessment year 2010-11 were higher than that obtained for the year 2009-10 by the factor of 1.0 to 2.5 $\mu\text{g/g}$. It is expected that results of present investigation will help in rational planning of pollution control strategies so as to reduce the toxicity impact on marine life of Vasai Creek.

Keywords Toxic Heavy Metals, Sediments, Marine Life, Quantification, Atomic Absorption Spectroscopy, Cold Vapour Technique, Vasai Creek, Mumbai, India

1. Introduction

Heavy metals are among the most common environmental pollutants, and their occurrence in waters and biota indicate the presence of natural or anthropogenic sources. Their accumulation and distribution in soil, water and environment are increasing at an alarming rate causing deposition and sedimentation in water reservoirs and affecting aquatic organisms as well[1-5]. Heavy metals like chromium, lead, cadmium, arsenic, etc. exhibit extreme toxicity even at trace levels. Creeks and Rivers are dominant pathways for metals transport[6,7] and heavy metals become significant pollutants of these water bodies[8]. These toxic metals not only pollute the aquatic systems but also pose a threat to the aquatic biota. The increase in residue levels of heavy metal content in water, sediments and biota, will result in decreased productivity [9] and increase in health risk in case of human beings[10-13]. The behaviour 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[8,14,15] which affect their behaviour and bioavailability[16,17]. For better understanding of heavy metal sources, their accumulation in the sediment and in water seem to be particularly

important issues of present day research on risk assessments.

In hydrosphere, toxic metal concentrations are typically orders of magnitude greater in the sediments as compared to those in overlying waters. The capacity of sediments to concentrate trace levels of most of the metals 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 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 industrial pollution [18-27] has prompted us to carry the systematic and detail study of pollution due to toxic heavy metals in sediments of Vasai Creek which due to rapid urbanisation and industrialisation is considered as one of the highly polluted creeks of Mumbai.

2. Materials and Methods

2.1. Area of Study

Vasai Creek is an estuarine creek, one of the two main distributaries of the Ulhas Creek in Maharashtra state of western India. The Ulhas Creek splits at the northeast corner of Salsette Island into its two main distributaries, Vasai Creek and Thane Creek. Vasai Creek which lies between latitude 19.315°N longitude 72.875°E, forms the northern

* Corresponding author:

pravinsingare@gmail.com (Pravin U. Singare)

Published online at <http://journal.sapub.org/chemistry>

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boundary of Salsette Island, and empties west into the Arabian Sea. The Creek receives domestic raw sewage as well as industrial waste water effluent from surrounding habitation and nearby industrial belt. The activities like cattle washing, cloth washing, and religious activities like immersion of idols of Lord Ganesha and Deity Durga during Ganesh festival and Navratri festival is also a major source of pollution of creek water.

2.2. Climatic Conditions

Climate is subtropical, with mild winters and warm summers. The weather is typical coastal sultry and humid. The average rainfall of records from 1500 mm to 2000 mm. The place experiences the onset of the monsoon in the month of June and experiences monsoon till the end of September. The average temperature recorded in varies from 25 to 37 degrees.

2.3. Requirements

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

2.4. Sediment Sampling and Preparation

The sediment samples were collected randomly four times in a month in morning, afternoon and evening session at four different sampling stations namely Vasai Bundar (*S-1*), Bhayandar west side of Railway Bridge (*S-2*), Bhayandar east side near Reti Bundar (*S-3*), and Ghodbundar site (*S-4*) along the Vasai Creek (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 [28]. They were then ground manually to a fine powder in an alumina mortar; it is passed through a 2-mm mesh screen and stored in polyethylene bags and kept in a dry place until analyses. Well-mixed samples of 2 g each were taken in 250 mL glass beakers and digested with 8 mL of aqua regia on a sand bath for 2 h. After evaporation to near dryness, the samples were dissolved with 10 mL of 2% nitric acid, filtered through Whatman's No. 1 filter paper and

then diluted with deionised water to give final volumes depending on the suspected level of the metals [29]. The samples were subjected to nitric acid digestion using the microwave-assisted technique, setting pressure at 30 bar and power at 700 watts [30, 31]. 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 [32]. 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 [33]. The sample solution was then aspirated into air acetylene flame in an atomic absorption spectrophotometer.

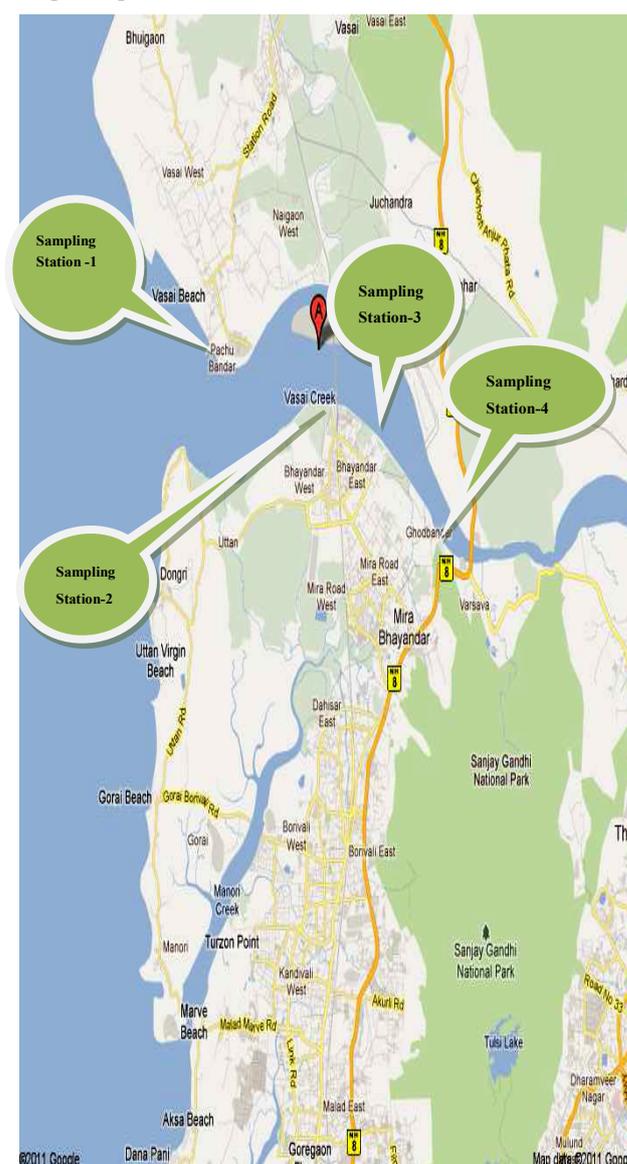


Figure 1. Map Showing Sampling Stations along Vasai Creek of Mumbai

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. The calibration curves were prepared separately for all the metals by running different concentrations of standard solutions. A reagent blank sample 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. All reagents were standardised against primary standards to determine their actual concentrations. All instruments used were calibrated 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 samples for Al, As, Cd, Cr, Ni, Pb, Sr, Mn and Hg.

3. Results and Discussion

Heavy metals, known to be potentially hazardous substances, are present in both natural and contaminated environments. In natural environments, they occur at low concentrations. However, at high concentrations as is the case in contaminated environments, they result in public health impacts. The elements that are of concern include nickel, cadmium, chromium, mercury, lead, strontium, manganese, Aluminum and arsenic. 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. The metals associated with particulate material are also available for biological uptake, and are deposited in estuarine sediments[34]. Once deposited, binding by sulfides and/or iron hydroxides immobilises trace metals until a change in redox or pH occurs[35]. Thus, surficial sediments, particularly the fine fraction, accumulate trace metals and provide a means for evaluating the long term accumulation of heavy metal contaminants[36]. The study of such trace and toxic heavy metals in the environment is more important in comparison to other pollutants due to their non-bio-degradable nature, accumulative properties and long biological half lives. These toxic heavy metals can be absorbed by green plants, which are primary producers in the ecosystem.

As they move up the food chain from producers to consumers, they endanger the public health by bioaccumulating in the plant and animal tissues and can cause physiological and neurological disorders

The experimental data on concentration ($\mu\text{g/g}$) of toxic heavy metals like Al, As, Cd, Cr, Hg, Ni, Pb, Sr and Mn in the sediment samples collected along sampling stations S1, S2, S3 and S4 of Vasai Creek is presented in Table 1. The trend in average concentration of these metals at different sampling stations for two assessment years 2009-10 and 2010-11 is graphically represented in Figures 2-5. From the results it was observed that Aluminum (*Al*) concentration at different sampling stations lies in the range of 84-278, 101-932, 74-448 and 35-398 $\mu\text{g/g}$ at the respective sampling stations. The biyearly average *Al* concentration was found to be 178, 562, 219 and 226 $\mu\text{g/g}$ 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 1.03 at S2 to 1.68 at S1 (Figures 2-5). It is important here to note that *Al* toxicity is a potential growth-limiting factor for plants grown in acid soils in many parts of the world [37]. The major *Al* toxicity symptom observed in plants is inhibition of root growth [38]. The roots exhibit greater signs of cellular damage than other parts of the plant [39]. *Al* toxicity could be observed in the root system particularly in root-tips and in lateral roots; lateral roots become thickened and turn brown [40]. The root system as a whole is coralloid in appearance with many stubby lateral roots but lacks fine branching. 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].

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 [42]. 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 [43]. *As* 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, 47]. In the present investigation it was observed that *As* concentration at S1, S2, S3 and S4 sampling stations lies in the range of 23-175, 71-429, 82-279 and 61-308 $\mu\text{g/g}$ respectively. The biyearly average *As* concentration was found to be 112, 285, 159 and 163 $\mu\text{g/g}$ 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 1.16 at S3 to 1.42 at S4 (Figures 2-5).

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

Heavy Metals Sampling Stations Month-Year	Al				As				Cd				Cr							
	S1	S2	S3	S4																
Oct-09	190	720	275	156	125	332	115	99	228	149	146	123	248	108	173	292				
Nov	120	788	272	170	136	399	120	90	299	128	108	118	227	178	165	275				
Dec	122	789	273	269	138	301	128	88	281	127	106	117	229	177	162	277				
Jan-10	126	789	271	266	139	300	137	87	289	130	107	119	226	179	167	274				
Feb	128	790	271	271	137	301	180	88	300	129	109	120	228	178	169	278				
March	173	730	245	300	125	327	226	208	335	116	118	166	288	292	345	295				
April	175	729	246	350	126	326	228	210	336	118	120	169	287	291	340	298				
May	175	731	245	398	124	326	229	207	335	134	119	167	385	293	343	299				
June	106	132	74	200	25	228	127	168	137	87	70	98	188	192	247	127				
July	116	150	83	168	24	108	101	141	125	48	83	63	147	108	184	102				
Aug	85	198	88	43	25	80	91	122	128	49	62	54	149	106	152	91				
Sept	84	101	105	35	23	71	82	115	127	47	55	45	147	107	121	82				
Oct	187	400	153	163	24	229	119	192	328	106	96	62	248	127	167	80				
Nov	227	588	171	179	141	298	176	189	315	128	109	120	229	177	166	171				
Dec	228	589	172	280	142	301	175	191	317	131	111	121	231	179	164	276				
Jan-11	230	690	270	367	140	300	180	190	400	130	110	120	330	180	170	280				
Feb	229	791	371	181	141	402	279	289	418	129	109	122	429	279	269	281				
March	275	830	448	201	155	427	227	307	438	170	127	168	589	394	347	296				
April	277	932	349	300	156	429	226	306	436	191	149	171	588	395	351	399				
May	278	835	350	365	175	428	228	308	437	202	160	170	590	395	350	400				
June	176	433	148	181	114	227	127	107	138	103	108	109	191	293	248	197				
July	189	335	123	198	114	231	112	83	128	78	99	100	148	208	299	155				
Aug	190	220	117	195	115	230	103	77	130	50	78	87	150	210	308	143				
Sept	188	198	125	193	114	231	94	61	127	51	76	91	149	209	297	129				
Average	178	562	219	226	112	285	159	163	272	114	106	117	276	219	238	229				
Range	84-278	101-932	74-448	35-398	23-175	71-429	82-279	61-308	125-438	47-202	55-160	45-170	147-590	106-395	121-351	80-400				
Median	181	516.5	261	216.5	99	250	180.5	184.5	281.5	124.5	107.5	108	368.5	250.5	236	240				
Heavy Metals Sampling Stations Month-Year	Hg				Ni				Pb				Sr				Mn			
	S1	S2	S3	S4																
Oct-09	121	119	55	24	125	58	88	167	277	267	176	253	119	48	87	45	218	165	79	87
Nov	128	115	48	14	132	81	71	157	225	275	165	272	114	74	65	59	228	184	65	68
Dec	126	117	46	19	135	88	74	171	228	278	162	375	116	77	67	63	225	186	68	71
Jan-10	127	119	45	17	133	86	76	176	224	276	163	377	112	79	69	65	327	289	66	74
Feb	124	108	37	18	137	87	77	275	227	279	165	480	115	77	66	67	428	390	67	76
March	117	98	58	15	364	91	82	300	345	220	242	588	315	281	71	185	475	475	120	165
April	115	96	59	18	367	98	95	304	348	218	244	591	318	284	84	287	528	478	124	267
May	118	95	57	19	364	135	94	303	349	221	247	594	320	287	146	291	429	479	125	366
June	19	37	20	8	169	77	17	205	247	122	149	295	119	289	45	194	230	281	67	159
July	18	25	17	5	125	52	23	165	174	65	136	235	115	44	38	102	115	265	53	121
Aug	14	13	19	4	128	57	20	151	76	62	123	189	118	47	33	90	118	167	45	92
Sept	16	11	23	8	126	55	18	132	79	63	118	156	117	49	23	73	216	169	37	84
Oct	117	56	35	10	189	156	66	169	77	164	154	199	216	50	57	165	218	171	59	163
Nov	125	75	55	14	191	182	75	175	126	274	265	274	215	75	65	207	125	285	65	274
Dec	128	89	68	19	195	188	78	179	225	277	367	376	217	108	71	268	128	387	68	278
Jan-11	130	90	60	20	240	190	80	180	330	380	470	480	320	180	70	370	230	390	70	330
Feb	132	90	71	18	238	187	79	281	429	381	571	579	421	181	89	371	331	391	66	379
March	118	157	84	24	366	232	92	304	554	518	644	590	514	286	144	390	525	475	126	461
April	117	175	88	28	372	235	97	357	557	523	647	597	519	288	148	395	528	478	227	565
May	120	180	90	30	370	238	118	398	560	525	650	698	422	290	150	399	530	582	330	670
June	39	25	21	11	269	137	79	308	361	326	351	396	221	291	109	298	331	381	129	371
July	27	20	34	15	224	155	63	289	374	268	289	355	116	48	100	243	317	368	115	255
Aug	20	20	29	13	230	160	60	256	380	270	263	301	120	50	93	172	320	370	113	189
Sept	39	19	33	14	228	158	53	248	377	266	202	287	109	49	95	167	319	371	118	192
Average	90	81	48	16	226	133	70	235	298	272	290	397	225	147	83	207	310	341	100	240
Range	14-132	11-180	17-90	4-30	125-372	52-238	17-118	132-398	76-560	62-525	118-650	156-698	109-519	44-291	23-150	45-399	115-530	165-582	37-330	68-670
Median	73	95.5	53.5	17	248.5	145	67.5	265	318	293.5	384	427	314	167.5	86.5	222	322.5	373.5	183.5	369

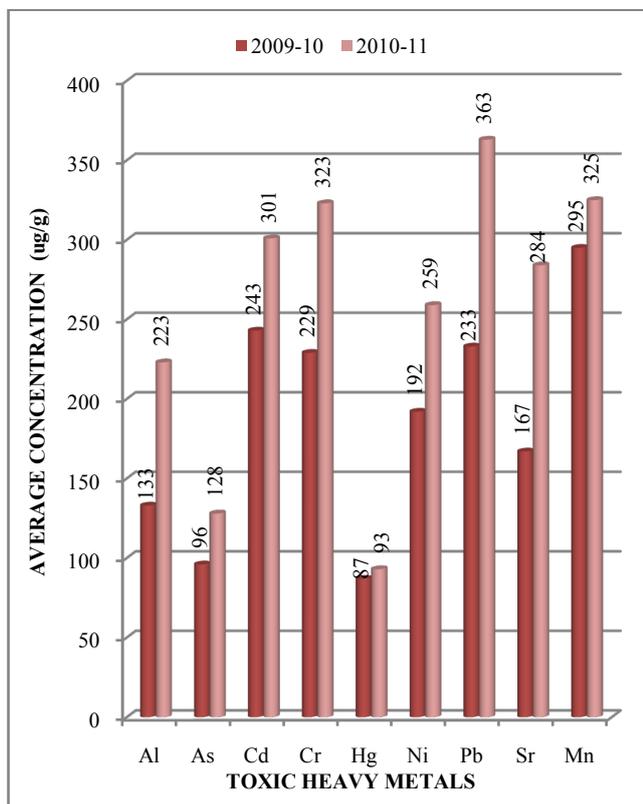


Figure 2. Variation in average concentration values of different toxic heavy metals in sediment samples collected at S-1 sampling station of Vasai Creek during the assessment year 2009-10 and 2010-1

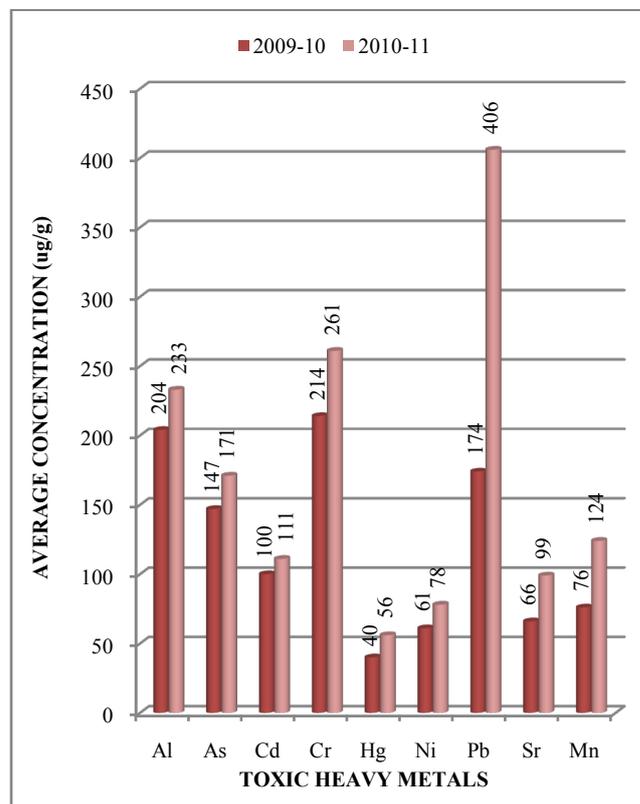


Figure 4. Variation in average concentration values of different toxic heavy metals in sediment samples collected at S-3 sampling station of Vasai Creek during the assessment year 2009-10 and 2010-11

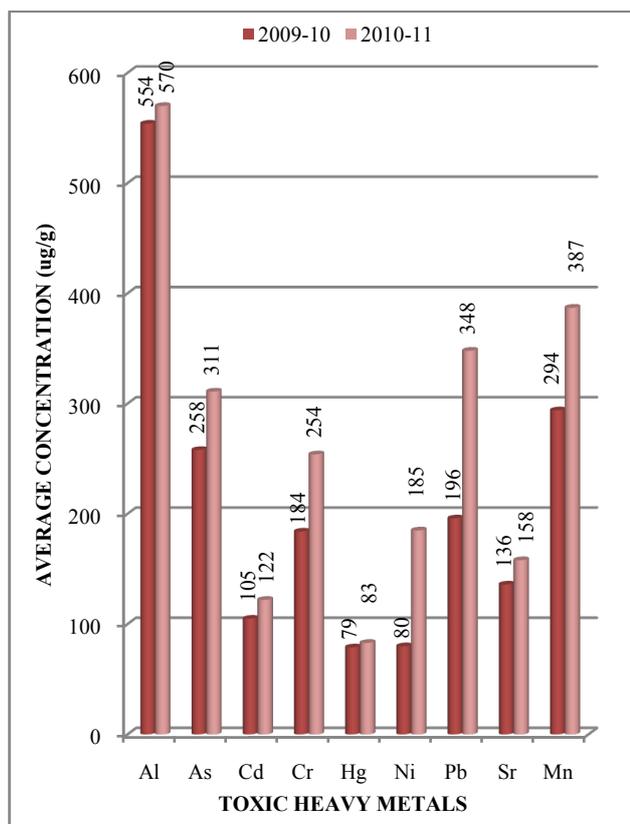


Figure 3. Variation in average concentration values of different toxic heavy metals in sediment samples collected at S-2 sampling station of Vasai Creek during the assessment year 2009-10 and 2010-11

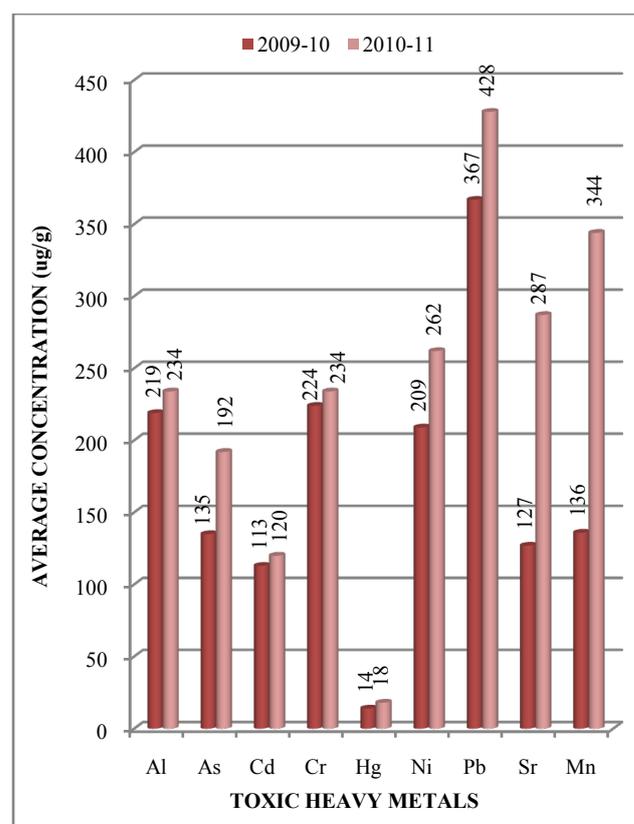


Figure 5. Variation in average concentration values of different toxic heavy metals in sediment samples collected at S-4 sampling station of Vasai Creek during the assessment year 2009-10 and 2010-11

Cadmium (*Cd*), a non-essential element, is one of the most toxic[48] and mobile heavy metals widely distributed in natural waters as a result of human activities[49]. It is a very important source of environmental pollution due to its bioavailability (it is less strongly complexed than other divalent heavy metals and, consequently, more toxic) and to its multiple technological applications (batteries, pigments, polymer stabilisation, etc.). The acute toxicity of waterborne cadmium on aquatic organisms is highly variable even among phylogenetically closely related species and depends on metal speciation, being the free ion (Cd^{2+}) form particularly toxic. Ferrari and Salibián[50] found that low concentrations of Cd^{2+} induced severe damage to the skin of *Bufo arenarum* tadpoles by the disruption of epithelial cell junctions, mainly in the absence of calcium ions in the solution. In the present investigation it was observed that *Cd* concentration at S1, S2, S3 and S4 sampling stations lies in the range of 125-438, 47-202, 55-160 and 45-170 $\mu\text{g/g}$ respectively. The biyearly average *Cd* concentration was found to be 272, 114, 106 and 117 $\mu\text{g/g}$ 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 1.06 at S4 to 1.24 at S1 (Figures 2-5).

In natural waters, fish are often exposed to chromium (*Cr*) waste and demonstrate cumulative deleterious effects as a function of time. Steinhagen *et al.*[51] examined the effect of *Cr* on carp (*Cyprinus carpio*)-derived immune cells. The results demonstrated that at concentrations between 2 and 200 $\mu\text{mol L}^{-1}$ *Cr*, the metal induced cytotoxicity and decreased the activation of mitogen-induced lymphocytes, as well as phagocyte functions. Neutrophils showed changes in cell shape together with reduced nitric oxide and reactive oxygen production at concentrations much lower than for the cytotoxic effects. The altered lymphocyte and neutrophil functions reflect the decreased resistance to pathogens observed in fishes under chronic *Cr* challenge. In the present investigation it was observed that *Cr* concentration at S1, S2, S3 and S4 sampling stations lies in the range of 147-590, 106-395, 121-351 and 80-400 $\mu\text{g/g}$ respectively. The biyearly average *Cr* concentration was found to be 276, 219, 238 and 229 $\mu\text{g/g}$ 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 1.04 at S4 to 1.41 at S1 (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[52]. Toxic effects of mercury in plants include abscission of older leaves, growth reduction, decreased vigour inhibition of root and leaf development, decreased chlorophyll content and nitrate reductase activity[53]. Other adverse effects caused by excessive mercury include membrane structure integrity disruption[54], mineral nutrient uptake reduction[55] and photosynthesis and transpiration reduction[56]. Higher concentrations ($> 1-2 \text{ mg/l}$) of mer-

cury decreased the growth of pea, tomato[55] and alfalfa[57]. Mercury also inhibited water uptake through aquaporins in plasma membrane in wheat[58]. Inhibition of enzymes of different metabolic pathways has also been reported by mercury toxicity[59]. In the present investigation it was observed that *Hg* concentration at S1, S2, S3 and S4 sampling stations lies in the range of 14-132, 11-180, 17-90 and 4-30 $\mu\text{g/g}$ respectively. The biyearly average *Hg* concentration was found to be 90, 81, 48 and 16 $\mu\text{g/g}$ 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 1.05 at S2 to 1.40 at S3 (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 [60]. 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[61]. 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[62]. 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[63]. 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[64,65]. While no reproductive effects have been associated with nickel exposure to humans, several studies on laboratory animals have demonstrated fetotoxicity[63,66]. In the present investigation it was observed that *Ni* concentration at S1, S2, S3 and S4 sampling stations lies in the range of 125-372, 52-238, 17-118 and 132-398 $\mu\text{g/g}$ respectively. The biyearly average *Ni* concentration was found to be 226, 133, 70 and 235 $\mu\text{g/g}$ 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 1.25 at S4 to 2.31 at S2 (Figures 2-5).

Lead (*Pb*) is not essential for plants, and excessive amounts can cause growth inhibition, as well as reduced photosynthesis, mitosis, and water absorption. The decline of some European spruce forests has been attributed to excessive concentrations of atmospheric *Pb*[67]. Lead is toxic to all phyla of aquatic biota, though effects are modified significantly by various biological and abiotic variables. Wastes from *Pb* mining activities have severely reduced or eliminated populations of fish and aquatic invertebrates, either

directly through lethal toxicity or indirectly through toxicity to prey species. Health advisories warning anglers against eating *Pb*-contaminated fish have been posted in Missouri [68]. In the present investigation it was observed that *Pb* concentration at S1, S2, S3 and S4 sampling stations lies in the range of 76-560, 62-525, 118-650 and 156-698 $\mu\text{g/g}$ respectively. The biyearly average *Pb* concentration was found to be 298, 272, 290 and 397 $\mu\text{g/g}$ 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 1.17 at S4 to 2.33 at S3 (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 S1, S2, S3 and S4 sampling stations lies in the range of 109-519, 44-291, 23-150 and 45-399 $\mu\text{g/g}$ respectively. The biyearly average *Sr* concentration was found to be 225, 147, 83 and 207 $\mu\text{g/g}$ 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 1.16 at S2 to 2.26 at S4 (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[69]. 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[70]. The growth of certain nuisance organisms is also supported by manganese[69,71]. 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 leaf and brown spots on leaves. In the present investigation it was observed that *Mn* concentration at S1, S2, S3 and S4 sampling stations lies in the range of 115-530, 165-582, 37-330 and 68-670 $\mu\text{g/g}$ respectively. The biyearly average *Mn* concentration was found to be 310, 341, 100 and 240 $\mu\text{g/g}$ 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 1.10 at S1 to 2.53 at S4 (Figures 2-5).

4. Conclusions

Although in India the Central Pollution Control Board (*CPCB*) is responsible for restoration and maintaining the wholesomeness of aquatic resources under Water Prevention and Control of Pollution Act 1974 passed by Indian Parliament, it is expected that to maintained or restored the quality of aquatic resources at desired level it is important to have monitoring on regular basis. Although much work has been done on pollution of aquatic resources due to toxic heavy metals, there is still a great need for information on influences of metals and their toxicities fully. The real problem today is not whether heavy metals are toxic or not, since we know that they are: but what concentrations are permissible/safe levels in our waters which do not produce harmful effects on users of water and biological life from the waters. Although it is impossible to prevent pollution of aquatic environment totally, but metal pollution and toxicity could be minimized by certain precautionary measures like development of adequate environmental control and management programmes and by continuous scientific monitoring of our aquatic environment. The present study on monitoring of toxic heavy metals in sediments will help to provide a means for evaluating the long term accumulation of heavy metal contaminants. The present study on pollution due to toxic heavy metals in the sediment samples collected along the Vasai Creek of Mumbai will be useful for rational planning of pollution control strategies and their prioritisation; to assess the nature and extent of pollution control needed and to evaluate effectiveness of pollution control measures already is existence.

ACKNOWLEDGEMENTS

The authors are thankful to SAP Productions for developing and maintaining the paper template.

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