

Heavy Metal Pollution in Mithi River of Mumbai

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Abstract The present study highlight the toxicity levels of different heavy metals in aquatic environment of one of the most polluted river of Mumbai- the Mithi River. Although the river has attracted tremendous attention after 26/7 flood in Mumbai, the pollution level of the river has remained neglected issue. The present study was performed for two assessment years 2009-10 and 2010-11 at three different sampling stations namely Airport, CST Kalina and BKC Taximen's Colony along the flow of Mithi River. The results of present investigation indicates that the concentration levels of most of the heavy metals like Al, As, Cd, Cr, Hg, Ni, Pb, Sr and Mn obtained during the assessment year 2010-11 was higher than that obtained during 2009-10 by the factor of 1.4 to 5.7 $\mu\text{g/L}$. The environmental impact of these toxic heavy metals is discussed. The results point out the need of rational planning of pollution control strategies, so as to keep check on release of toxic heavy metals in the river. It is expected that the present study will be useful for rational planning of pollution control strategies and their prioritisation; to evaluate effectiveness of pollution control measures already is existence and to assess the nature and extent of pollution control needed.

Keywords Heavy Metals, Water Pollution, Toxicity, Environmental Impact, Mithi River, Mumbai, India

1. Introduction

Heavy metals are considered very important and highly toxic pollutants in the various environmental departments. Ecotoxicologists and environmental scientists use the term "heavy metals" to refer to metals that have caused environmental problems. Heavy metals including both essential and non-essential elements have a particular significance in ecotoxicology, since they are highly persistent and all have the potential to be toxic to living organisms[1]. The metals which have been studied extensively the last decades are: Cd, Hg, Zn, Cu, Ni, Cr, Pb, Co, V, Ti, Fe, Mn, Ag and Sn. Some metals that have received more attention are Hg, Cd, and Pb, because of their highly toxic properties and their effects on the environment and the living organisms. Inputs of these toxic heavy metals to the environment as a result of anthropogenic activities is difficult to measure due to the very large natural inputs from the erosion or rocks, wind-blowing dusts, volcanic activity and forest fires. Atmospheric and river inputs, dredging spoil, direct discharges, industrial dumping and sewage sludge are some of the important contributors to metal pollution, which lead to the release of toxic heavy metals to the marine environment. Some metals enter the sea from the atmosphere, e.g. natural inputs of metals, such as Aluminium (Al) in wind-blowing dust of rocks and shales, and mercury (Hg) from volcanic activity. Lead (Pb) inputs in the atmosphere from industrial and vehicular

exhaust are much greater than natural inputs. Some metal-sare deposited by gas exchange at the sea surface, by fallout of particles (dry deposition) or are scavenged from the air column by precipitation (rain) which is called wet deposition. The nature of metals depends on ore-bearing deposits in the catchment area and the discharge of human waste when the river passes through urban areas. Dredging of shipping channels produces large quantities of metal pollution. Much smaller quantities of metals are added to the sea by direct discharges of industrial and other waste and the dumping of sewage sludge[2]. Acid rain resulting from dissolved hydrogen sulphide, sulphur dioxide and oxides of nitrogen has contributed to alterations of soil and freshwater acidity. As a consequence there is an increase in the bioavailability of many heavy metals to freshwater biota[3].

Metals are separated into the essentials and non-essentials in classes A and B, and in a borderline class[2].

Class A metals: Calcium (Ca), Magnesium (Mg), Manganese (Mn), Potassium (K), Sodium (Na), Strontium (Sr)

Class B metals: Cadmium (Cd), Copper (Cu), Mercury (Hg), Silver (Ag)

Borderline metals: Zinc (Zn), Lead (Pb), Iron (Fe), Chromium (Cr), Cobalt (Co) Nickel (Ni), Arsenic (As), Vanadium (V), Tin (Sn).

The world-wide emissions of metals to the atmosphere (thousands of tons per year) by natural sources is estimated as: Ni: 26, Pb: 19, Cu: 19, As: 7.8, Zn: 4, Cd: 1.0, Se: 0.4, ($\times 10^3$ tons. Year⁻¹). Whereas, from anthropogenic sources: Pb: 450, Zn: 320, Ni: 47, Cu: 56, As: 24, Cd: 7.5, Se: 1.1 ($\times 10^3$ tons. Year⁻¹). It is obvious from these numbers that Pb, Zn, Ni and Cu are the most important metal pollutants from human activities[4]. Heavy metal pollution of freshwater

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

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ecosystems has been shown to be extensive[5]. Rivers make a major contribution of metals in the marine environment and are considered as a dominant pathway for metals transport[6]. As a result heavy metals become significant pollutants of many riverine systems. 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[7,8] which affect their behaviour and bioavailability[9]. Hence, heavy metals are sensitive indicators for monitoring changes in the aquatic environment.

The preservation of aquatic resources for ecosystem and human health and well-being is a paramount concern worldwide and it has become evident that approaches to managing aquatic resources must be undertaken within the context of ecosystem dynamics in order that their exploitation for human uses remains sustainable[10]. If aquatic resources are not properly managed and aquatic ecosystems deteriorate, then human health and well-being may be compromised. Water quality monitoring for the detection of trends, impacts, and improvements is further complicated because the issues of concern and available resources are constantly changing[11]. Although it is not always possible to predict new and emerging threats to aquatic ecosystems, baseline water quality monitoring must be maintained to facilitate the early detection of such threats. The success of local, regional, and global efforts to curb rates of water quality degradation can only be measured if sufficient data are available that enable the tracking of trends over time and space.

The problem of water quality degradation due to toxic heavy metals has begun to cause concern now in most of the major metropolitan cities in Maharashtra state of India and Mumbai is not an exception to it. The day by day deteriorating quality of water bodies in the country[12-22] has prompted us to carry the systematic and detail study of pollution due to toxic heavy metals in water of Mithi River, which due to rapid urbanisation and industrialisation is considered as one of the highly 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.

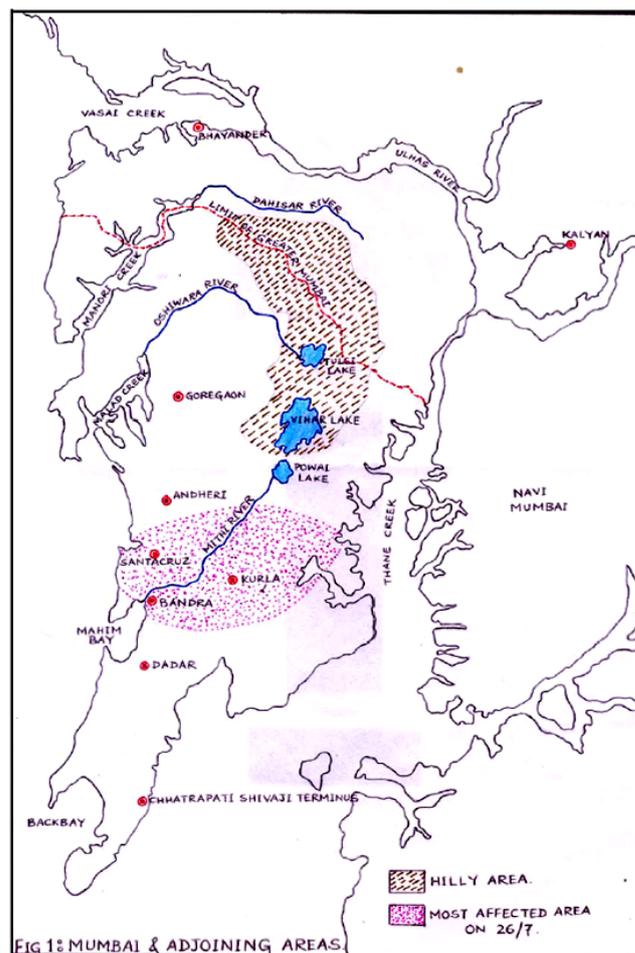


Figure 1. Map showing flow of Mithi River in Mumbai

2.2. Climatic Conditions

The area is located along western Arabian coast 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 acid soaked (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 traces of cleaning reagents. The pipettes and burette were rinsed with solution before final use.

2.4. Water Sampling and Sample Preparation

The water samples were collected randomly twice in a month in morning, afternoon and evening session from three different sampling stations along the flow of Mithi River. 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. Polythene bottles of 2.5 L and 2.0 L were used to collect the grab water samples (number of samples collected, $n = 19$). The bottles were thoroughly cleaned with hydrochloric acid, washed with tap water to render free of acid, washed with distilled water twice, again rinsed with the water sample to be collected and then filled up the bottle with the sample leaving only a small air gap at the top. The sample bottles were stoppered and sealed with paraffin wax. Water samples (500 mL) were filtered using Whatman No. 41 (0.45 μm pore size) filter paper for estimation of dissolved metal content. Filtrate (500 mL) was preserved with 2 mL nitric acid to prevent the precipitation of metals. The samples were concentrated to tenfold on a water bath and subjected to nitric acid digestion using the microwave-assisted technique, setting pressure at 30 bars and power at 700 Watts[23,24]. 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[25]. 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[26]. 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 alu-

minium (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 absorption spectrophotometer. The calibration curves were prepared separately for all the metals by running different concentrations of standard solutions. A reagent blank sample was 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

Water samples were collected in polythene bottles 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 samples for Al, As, Cd, Cr, Ni, Pb, Sr, Mn and Hg.

3. Results and Discussion

A number of elements are normally present in relatively low concentrations, usually less than a few mg/L, in conventional irrigation waters and are called trace elements. Heavy metals are a special group of trace elements which have been shown to create definite health hazards when taken up by plants. Under this group are included, Cr, Cd, Ni, Zn, Cu, Pb and Fe. These are called heavy metals because in their metallic form, their densities are greater than 4 g/cc. The experimental data on concentration ($\mu\text{g/L}$) of toxic heavy metals like Al, As, Cd, Cr, Hg, Ni, Pb, Sr and Mn in the water 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 two assessment years 2009-10 and 2010-11 is graphically represented in Figures 2-4.

The effects of aluminium (Al) have drawn our attention, mainly due to the acidifying problems. Al may accumulate in plants and cause health problems for animals that consume these plants. The concentrations of Al appear to be highest in acidified aquatic environment[27]. In such aquatic environment the number of fish and amphibians is declining due to reactions of aluminium ions with proteins in the gills of fish and the embryo's of frogs[28].

Table 1. Heavy Metal Content in Water Samples Collected at different Sampling Stations along Mithi River of Mumbai (values in µg/L)

Heavy Metals	Al			As			Cd			Cr			Hg			Ni			Pb			Sr			Mn		
	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
Month-Year																											
October-09	7	16	20	19	57	67	16	10	31	28	85	112	40	9	15	317	55	330	154	114	340	64	96	78	92	58	88
November	6	14	17	20	61	71	18	12	36	31	92	121	35	8	13	292	52	336	139	105	325	61	88	91	106	67	97
December	8	21	25	19	56	66	15	10	30	28	83	108	40	9	15	276	56	331	125	83	343	59	104	95	110	69	92
January-10	8	19	23	17	52	60	13	9	27	23	76	105	42	10	13	304	56	352	116	58	352	55	103	102	115	77	103
February	10	26	31	17	50	58	14	10	29	30	89	117	44	10	17	281	48	379	133	64	341	57	91	88	83	73	82
March	12	30	37	17	52	61	15	10	30	33	100	131	49	12	19	272	40	387	141	72	289	53	86	93	88	72	96
April	13	33	40	19	58	67	19	13	38	40	121	158	48	11	18	212	38	405	146	80	239	55	88	96	106	78	108
May	20	51	61	28	84	98	20	13	40	55	166	217	54	13	20	232	45	381	153	88	260	57	90	102	109	82	117
June	11	28	34	14	41	48	14	19	6	76	6	16	21	10	8	111	26	105	118	68	178	40	56	54	50	31	89
July	9	21	26	10	31	36	7	9	3	85	7	18	14	7	6	68	18	41	106	56	99	16	21	21	31	12	29
August	6	15	18	7	21	25	3	4	1	93	8	22	8	8	5	16	9	17	103	50	27	4	5	8	9	3	16
September	5	14	16	7	20	23	4	6	2	75	8	23	9	5	3	34	13	31	94	55	73	6	11	14	6	6	19
October	20	59	68	76	267	297	78	65	196	71	213	234	72	16	18	539	94	495	247	159	747	198	269	188	194	169	132
November	17	52	60	81	283	315	89	74	223	77	231	254	63	14	16	496	88	505	223	147	716	189	246	217	223	194	146
December	25	75	88	75	263	293	74	62	186	69	207	228	72	16	18	469	96	497	200	116	755	182	291	228	231	201	138
January-11	33	11	22	57	29	86	14	14	28	91	15	76	281		31	250	36	36	192	115	77	214	72	36	117	17	17
February	31	92	108	67	226	259	71	55	157	75	224	246	80	18	20	478	82	569	213	90	749	178	255	211	174	213	123
March	37	110	128	70	236	271	75	58	166	83	250	275	89	20	22	463	68	580	226	101	636	163	241	223	185	208	145
April	40	119	139	77	262	300	95	73	208	101	302	332	87	19	22	360	65	607	234	112	527	172	247	231	222	226	162
May	61	182	213	113	383	439	100	77	219	138	414	455	97	22	24	395	76	571	245	123	571	176	252	244	228	239	175
June	34	102	119	55	186	264	69	110	34	189	16	33	38	60	10	189	44	157	188	95	392	124	156	130	106	90	133
July	26	77	89	41	89	125	33	53	17	212	18	38	25	44	7	115	30	62	170	79	218	51	58	49	65	36	44
August	23	21	8	35	71	28	71	13	13	9	19	18	51	25	22	72	132	72	25	75	92	72	22	17	15	24	35
September	16	48	57	26	29	19	22	34	11	188	21	48	16	30	4	59	22	47	150	78	160	19	30	34	13	17	28
AVERAGE	20	51	60	40	121	141	40	34	72	79	115	141	57	18	15	262	54	304	160	91	354	94	124	110	111	94	92
Range	5-61	11-182	8-213	7-113	20-383	19-439	3-100	4-110	1-223	9-212	6-414	16-455	8-281	5-60	3-31	16-539	9-132	17-607	25-247	50-159	27-755	4-214	5-291	8-244	6-231	3-239	16-175
Median	33	97	110	60	201	229	51	57	112	111	210	236	144	32	17	278	71	312	136	105	391	109	148	126	119	121	96

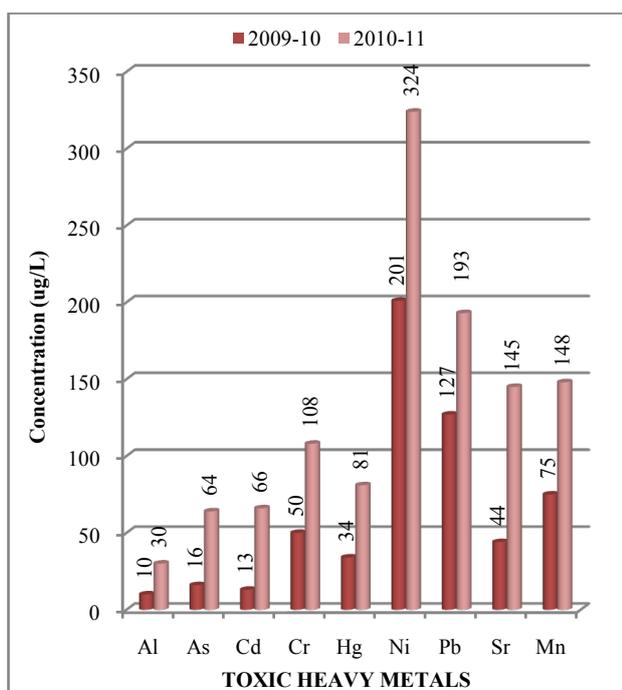


Figure 2. Variation in average concentration values of different toxic heavy metals in water samples collected at sampling station L-1 of Mithi River during the assessment year 2009-10 and 2010-11

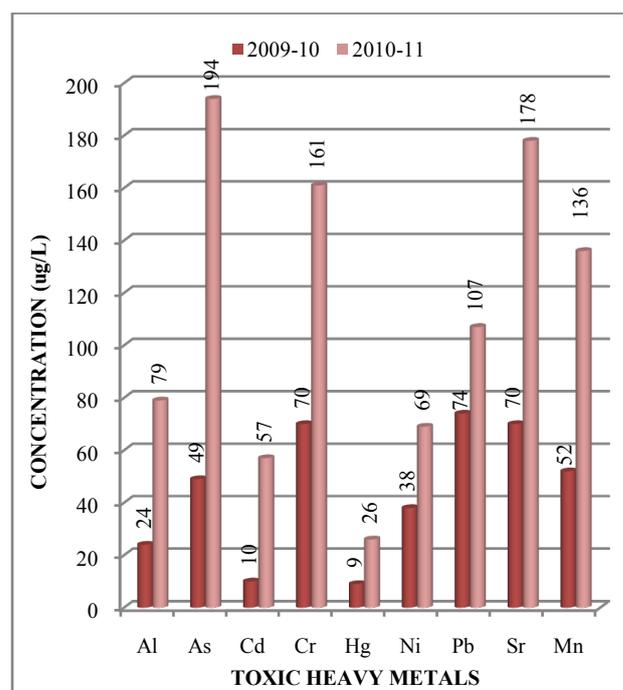


Figure 3. Variation in average concentration values of different toxic heavy metals in water samples collected at sampling station L-2 of Mithi River during the assessment year 2009-10 and 2010-11

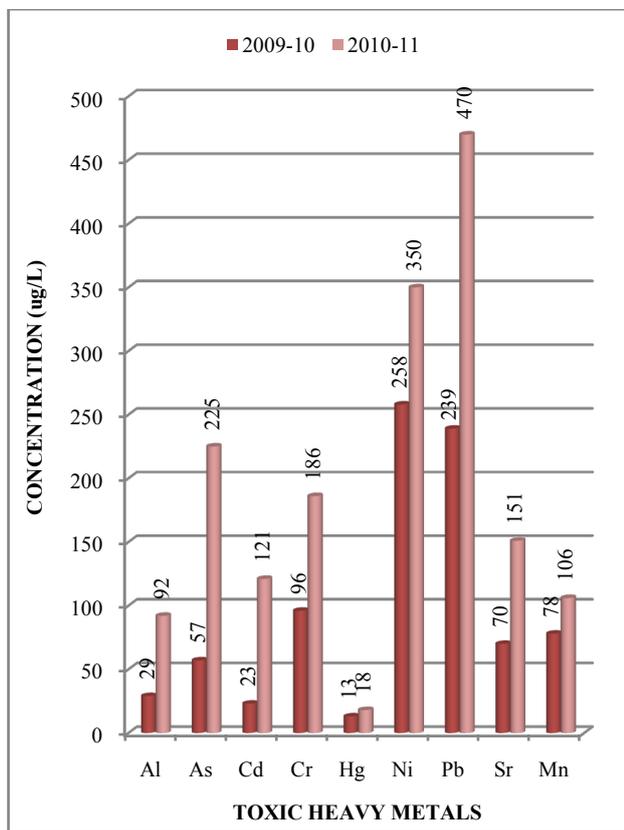


Figure 4. Variation in average concentration values of different toxic heavy metals in water samples collected at sampling station L-3 of Mithi River during the assessment year 2009-10 and 2010-11

From the results of present investigation it was observed that *Al* concentration at different sampling stations lies in the range of 5-61, 11-182 and 8-213 µg/L at L1, L2 and L3 sampling stations respectively. The biyearly average *Al* concentration was found to be 20, 51 and 60 µg/L 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 3.0 at L1 to 3.3 at L2 sampling stations (Figures 2-4).

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[29]. 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[30]. *As* can also interfere with the fish immune system by suppressing antibody production[31] as well as by lowering macrophage activity and maturation[32]. Several studies are reporting *As* induced liver fibrosis, hepatocellular damage, inflammation, focal necrosis in addition to hepatocellular carcinoma[33-35]. In the present investigation it was observed that *As* concentration at L1, L2 and L3 sampling stations lies in the range of 7-113, 20-383 and 19-439 µg/L respectively. The biyearly average *As* concentration was found to be 40, 121 and 141

µg/L 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 3.9 at L3 to 4.0 at L1 and L2 sampling stations (Figures 2-4).

Cadmium (*Cd*) is typically a metal of the 20th century, and is mainly used in rechargeable batteries and for the production of special alloys. It was the outbreak of the Itai-Itai bone disease in Japan in the 1960s that really drew the attention of the public and regulatory bodies to this heavy metal that had been discharged in the environment at an uncontrolled rate for more than one century. Although emissions in the environment have markedly declined in most industrialized countries, *Cd* remains a source of concern for populations living in polluted areas, especially in less developed countries[36]. *Cd* dispersed in the environment can persist in soils and sediments for decades. When taken up by plants, *Cd* concentrates along the food chain and ultimately accumulates in the body of people eating contaminated foods. 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[37], the bone, the respiratory tract[38] and other vital organs such the lungs or the liver. 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[39-41]. In the present investigation it was observed that *Cd* concentration at L1, L2 and L3 sampling stations lies in the range of 3-100, 4-110 and 1-223 µg/L respectively. The biyearly average *Cd* concentration was found to be 40, 34 and 72 µg/L 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 5.1 at L1 to 5.7 at L2 sampling stations (Figures 2-4).

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[42]. Besides the lungs and intestinal tract, the liver and kidney are often target organs for chromate toxicity[43]. In the present investigation it was observed that *Cr* concentration at L1, L2 and L3 sampling stations lies in the range of 9-212, 6-414 and 16-455 µg/L respectively. The biyearly average *Cr* concentration was found to be 79, 115 and 141 µg/L 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 1.94 at L3 to 2.30 at

L2 sampling stations (Figures 2-4).

Mercury (*Hg*) poisoning has become a problem of current interest as a result of environmental pollution on a global scale. High concentration of *Hg*, which could pose an ecological hazard, leading to contamination of plants, aquatic resources and bioaccumulation in the food chain[44]. 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. Bodaly et al.[45] have reported that treated sewage water discharged into rivers and similar water bodies could result in an appreciable increase in the build up of alkyl mercury. Further reports by Tanaka[46] and Goldstone et al.[47] have dwelt on the natural alkylation of total *Hg* in waste water and water bodies. In the present investigation it was observed that *Hg* concentration at L1, L2 and L3 sampling stations lies in the range of 8-281, 5-60 and 3-31 $\mu\text{g/L}$ respectively. The biyearly average *Hg* concentration was found to be 57, 18 and 15 $\mu\text{g/L}$ 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 1.38 at L3 to 2.89 at L2 sampling stations (Figures 2-4).

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. *Ni* is a nutritionally essential trace metal for at least several animal species, micro-organisms and plants, and therefore either deficiency or toxicity symptoms can occur when, respectively, too little or too much *Ni* is taken up. Although a number of cellular effects of nickel have been documented, a deficiency state in humans has not been described[48-50]. Although *Ni* is omnipresent and is vital for the function of many organisms, concentrations in some areas from both anthropogenic release and naturally varying levels may be toxic to living organisms[50-52]. *Ni* compounds have been well established as carcinogenic in many animal species and by many modes of human exposure but their underlying mechanisms are still not fully understood[53, 54]. *Ni* can cause cancer of the lungs and nasal passages. The most common effect of nickel exposure is an allergic reaction. Approximately 10-15% of the population is sensitive to nickel. The most common reaction is a rash at the site of contact. Less frequently, some people that are sensitive to nickel suffer asthma attacks after exposure. Some workers exposed to high levels of *Ni* have developed chronic bronchitis and changes to their lungs. In the present investigation it was observed that *Ni* concentration at L1, L2 and L3 sampling stations lies in the range of 16-539, 9-132 and 17-607 $\mu\text{g/L}$ respectively. The biyearly average *Ni* concentration was found to be 262, 54 and 304 $\mu\text{g/L}$ 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 1.36 at L3 to 1.82 at L2 sampling stations (Figures 2-4).

Ecological and toxicological aspects of lead (*Pb*) and its compounds in the environment have been extensively reviewed[55-63]. There is agreement by all authorities on five points. First, *Pb* is ubiquitous and is a characteristic trace constituent in rocks, soils, water, plants, animals, and air. Second, more than 4 million metric tons of *Pb* is produced worldwide each year, mostly for the manufacture of storage batteries, gasoline additives, pigments, alloys, and ammunition. The widespread broadcasting of *Pb* through anthropogenic activities, especially during the past 40 years, has resulted in an increase in *Pb* residues throughout the environment—an increase that has dislocated the equilibrium of the biogeochemical cycle of *Pb*. Third, *Pb* is neither essential nor beneficial to living organisms; all existing data show that its metabolic effects are adverse. Fourth, *Pb* is toxic in most of its chemical forms and can be incorporated into the body by inhalation, ingestion, dermal absorption, and placental transfer to the foetus. Fifth, *Pb* is an accumulative metabolic poison that affects behaviour, as well as the hematopoietic, vascular, nervous, renal, and reproductive systems. In the present investigation it was observed that *Pb* concentration at L1, L2 and L3 sampling stations lies in the range of 25-247, 50-159 and 27-755 $\mu\text{g/L}$ respectively. The biyearly average *Pb* concentration was found to be 160, 91 and 354 $\mu\text{g/L}$ 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 1.45 at L2 to 1.97 at L3 sampling stations (Figures 2-4).

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 *Sr* 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 4-214, 5-291 and 8-244 $\mu\text{g/L}$ respectively. The biyearly average *Sr* concentration was found to be 94, 124 and 110 $\mu\text{g/L}$ 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 2.16 at L3 to 3.30 at L1 sampling stations (Figures 2-4).

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[64]. 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[65]. The growth of certain nuisance organisms is also supported by manganese[64,66]. 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 leaves 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 6-231, 3-239 and 16-175 µg/L respectively. The biyearly average *Mn* concentration was found to be 111, 94 and 92 µg/L 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 1.36 at L3 to 2.62 at L2 sampling stations (Figures 2-4).

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 water quality at desired level it is important to have monitoring on regular basis. Also to address water quality related environmental problems, it is must to have accurate information and to know precisely what the problem is, where it is occurring, how serious it is, and what is causing it. Such information is necessary for determining cost effective and lasting solutions to water related problems. Hence it is expected that the regular water quality monitoring study as performed in the present investigation will help in understanding the water quality trends over a period of time and prioritising pollution control efforts. The present study will also be useful to assess assimilative capacity of a water body thereby reducing cost on pollution control; to assess the fitness of water for different uses.

ACKNOWLEDGEMENTS

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

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