Seasonal variation in heavy metal contamination in water and sediments of river Sabarmati and Kharicut canal at Ahmedabad, Gujarat

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Abstract The objective of the study is to reveal the seasonal variations in the river water and sediment quality with respect to heavy metal contamination. To get the extent of trace metals contamination, water and sediment samples were collected from five different sites along the course of Sabarmati River and its tributary Kharicut canal in pre-monsoon, monsoon and post-monsoon seasons. The concentration of trace metals such as chromium, copper, lead, nickel and zinc was determined using inductively coupled plasma spectroscopy. The concentrations of heavy metals were found to be higher in the pre-monsoon season than in the monsoon and post-monsoon seasons in water samples. The pollution load index, contamination factor and degree of contamination (C_d) in sediments were calculated to know the extent of anthropogenic pressures. The values of C_d clearly indicated very high degree of contamination at Kharicut canal (S-4: 32.25 and S-5: 54.52) and considerable degree of contamination at three sites of Sabarmati river viz; S-1, S-2 and S-3 with values 14.30, 14.42 and 17.21, respectively. Lead and nickel could not be traced in any of the river water samples.

Introduction

Pollution of underground water and surface water system through anthropogenic activities is the major environmental problem faced all around the globe. Heavy metals are widespread pollutants of great environmental concern as they are nondegradable, toxic and persistent with serious ecological ramifications on aquatic ecology (Aboud and Nandini 2009). During the last two centuries, heavy metals released by human activities have superimposed new pattern of metal distribution on those which are naturally occurring. Heavy metals are widely used in automobiles, mining industries, pesticides, house-holds appliances, dental amalgams, paints, photographic papers, photo chemicals, etc. (WHO 1998; Lohani et al. 2008). There are basically three reservoirs of metals in aquatic environment: water, sediment and biota. Metal levels in each of these three reservoirs are dominated by a complex

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dynamic equilibrium governed by a various physical, chemical and biological factors (Saha et al. 2001). The basins of many rivers extend over very densely populated areas and are subjected to intensive exploitation by both industrial and agricultural activities. Such activities often result in the introduction of nutrients and potentially hazardous levels of heavy metals into the riverine ecosystem. Once discharged into the environment, the behaviour and fate of polluting substances will be determined by the combined effects of different variables such as the compound's physicochemical properties, river hydrology and hydrochemistry. An assessment of sediment quality is recognized as a critical step in estimating the risks associated with man-made pollution in riverine systems (Kucuksezgin et al. 2008). The analysis of heavy metals in the sediments permits detection of pollutants that may be either absent or in low concentrations in the water column.

The Sabarmati River is one of the four major rivers which traverses the alluvial plains of Gujarat. It arises in the Aravalli hills at a north latitude of 24°40′ and east longitude of 73°20′ in the Rajasthan state at an elevation of 762 m above mean sea level. The total length of the river from the head to its outfall into the sea is 371 km. The river basin extends over an area of 21,674 sq km located in Western India and covers areas in the states of Rajasthan and Gujarat. The river is known to be under contamination menace by wastes derived from industrial sources, sewage and agricultural activities. The Sabarmati River Front Development project is an initiative taken by state government to revitalize the river and integrate it into the city's environmental, financial and cultural development .The progress of this project work has also created anthropogenic pressure on river ecosystem.

The Kharicut canal of Vatva is an extension from river Khari, a tributary of Sabarmati River. The canal was built with a purpose to provide irrigation facility to nearby villages of Ahmedabad which gradually has turned into a dumping site because of discharge from industrial units of Vatva GIDC that leads to deterioration of water body and poses serious risk to the human, animals and aquatic biota (Shah et al. 2008). The present study aimed to envisage the water quality status of Sabarmati River and Kharicut canal with respect to its heavy metal concentrations in various seasons at Ahmedabad, Gujarat.

Materials and methods

Study area

Ahmedabad is located at 23.03° N and 72.58° E at an average elevation of 53 m from the mean sea level spanning an area of 310 km^2. The river Sabarmati enters into Ahmedabad near Hansol and passes through the centre of the city with a stretch of approximately 20–25 km from north to south. Two study areas have been selected for present work.

1. Sabarmati River
2. Kharicut canal

Study area I—Sabarmati river Three sites viz site 1 Indira bridge (23°5′26″ N and 72°37′47″ E), site 2 Gandhi bridge (23°2′24″ N and 72°34′24″ E) and site 3 Sardar Patel bridge (23°0′40″ N and 72°34′27″ E) have been selected for present work (Fig. 1). The site 1 (Indira Bridge) is situated outside the main city near Kotarpur Village and surrounded by agricultural fields, whereas site 2 (Gandhi Bridge) and site 3 (Sardar Patel Bridge) are situated in the main city area and are approx. 4.5 and 9 km away from site 1, respectively. The work on Sabarmati river front Development is on fast pace at sites 2 and 3. It includes river dredging, construction of retaining walls, ghats, promenades, etc. These activities result in the influx of soil, cement and other particulate matter in the river which affects the quality of water.

Study area II—Kharicut canal Two sites, one near Jashodanagar (S-4; 22°59′7″ N and 72°37′44″ E) and other at Vatva GIDC phase IV (S-5; 22°58′11″ N and 72°39′11″ E) have been selected. These two sites receive industrial effluents from various industries likes plastic industry, light and heavy engineering, machinery and components, chemicals, paints, pharmaceuticals, foundries, textile, etc. Further in the "Results and discussion" section the above sites are termed as S-1, S-2, S-3, S-4 and S-5.

Sample collection and Analysis

The water and sediment samples for physico-chemical and heavy metal analysis were collected during three seasons, i.e. premonsoon (April and May), monsoon

Fig. 1 Site map of study area

(August and September) and post-monsoon (October and January) for the year 2009–2010. The water quality parameters such as temperature, pH and dissolved oxygen (DO) were measured in situ. The temperature was measured with mercury filled glass thermometer, pH with EiE instrument ATC model 132E pH metre and DO by Winkler method. Chemical oxygen demand (COD) by reflux digestion method, biochemical oxygen demand (BOD) by dilution method and total dissolved solids (TDS) by gravimetric method were measured at laboratory as per standard methods for the examination of water and waste water (APHA et al. 1998).

For heavy metal analysis, the water samples were collected in an acid-washed cleaned polyethylene bottles and filtered through Whatman filter paper No. 42 (2.4 μm pore size). The filtered samples were immediately acidified with 0.1 N HNO_3 to avoid precipitation of heavy metals (Wilken and Hintelman

1991) and refrigerated at 4°C till their use for heavy metal analysis.

The sediment samples were collected in ziplock polythene bags using a plastic scoop. The samples were brought to laboratory and were first air-dried and then oven dried at approx. 90°C. After that the dried sediments were crushed using mortar and pestle and sieved through <1 mm size nylon sieve for further analysis (Dalai et al. 2004). After thorough homogenization, 1 g of powdered sample was digested with mixture of HNO_3, H_2SO_4 and H_2O_2 (2:6:6 ratio) on hot plate (Saison et al. 2004; Kumar et al. 2009). At the end of digestion, the dried flasks were filled with double distilled water to make volume upto 20 ml and filtered through Whatman filter paper No.42.

The preserved water and sediment samples were analysed for heavy metals, viz lead (Pb), nickel (Ni), copper (Cu), zinc (Zn) and chromium (Cr) using the

inductive coupled plasma spectrometer, Perkin Elmer Optima 3000 RL model at the Sophisticated Instrumentation Centre for Applied Research and Testing (SICART), Vallabh Vidyanagar, Gujarat. The detection limits of Instrument for different heavy metals are Pb 0.0420 ppm, Ni 0.0150 ppm, Cu 0.0097 ppm, Zn 0.0059 ppm and Cr 0.0071 ppm.

The data obtained were analysed using the Ky plot Beta 2.0 version in order to obtain mean values and standard deviation. A correlation matrix test was carried out to check the significant relationship among five heavy metals and physico-chemical parameters (significance level 0.05).

Results and discussion

Water quality parameters such as dissolved oxygen, pH, temperature, BOD and COD clearly influence the distribution of pollutants and affect their fate in the riverine system (Kucuksezgin et al. 2008). The solubility of trace metals in surface water is predominately controlled by the water pH, temperature, the river flow and the redox environment of river system. A lower pH increases the competition between metal and hydrogen ions for binding sites. A decrease in pH may also dissolve metal carbonate complexes, releasing free metal ions into the water column (Papafilippaki et al. 2008). The concentration of basic physico-chemical parameters are summarized in Table 1 along with standard deviation. Table 2 depicts the correlation matrix among various water quality parameters and heavy metals. It is revealed that pH and temperature exhibited positive correlation with all the heavy metals except for Zn whereas DO showed negative correlation with almost all parameters, thus it can be served as a single useful index of water quality, as with rise in the

value of most of these parameters decreases the DO concentration (Khaiwal et al. 2003).

The pH values varied between 6.4 and 9.5 in the sampling sites. The lowest pH values were found during monsoon period due to rainfall. Water temperature varied between 18.4°C and 33°C, and normal seasonal variations were observed. The concentration of dissolved oxygen varied between 2.94 and 7.84 mg/l in river water and 0–0.88 mg/l at S-4 and S-5, i.e. in canal water. The DO content was the highest in post-monsoon season, i.e. in winter as lower temperature favours the dissolution of oxygen in water. The mean values of COD ranged between 23.38 and 661.37 mg/l at five sampling sites and were generally higher in pre-monsoon season. The highest COD was observed at S-4 and S-5 sites due to the industrial discharges. The BOD ranged between 3.23 and 15.87 mg/l in river water, and the highest values were found at S-2 and S-3 as it received significant amounts of domestic waste from the urban area. The mean concentration of TDS varied from 135.8 to 3,505.01 mg/l at five sampling stations and high levels were found at Kharicut canal where the discharge of industrial effluent is the point source of pollution.

The seasonal variation of heavy metals in sediments and water of Sabarmati and Kharicut canal is depicted in Fig. 2a–e and Fig. 3a–e, respectively. Table 3 summarizes the mean values of heavy metal concentration in water and sediments of Sabarmati and Kharicut canal. The concentration of heavy metals considered was far higher in the sediments than those calculated for the same heavy metals in the water samples.

Among all heavy metals, chromium was found to be the most abundant element. At S-1, S-2 and S-3, the mean concentration of chromium ranged from 6.50 mg/kg in post-monsoon season to 4,719.2 mg/kg in pre-monsoon season. Whereas at S-4 and S-5, the concentration of Cr was the highest in pre-monsoon season, i.e. 16,838 mg/kg and the lowest in post

Table 1 Mean concentration of various physico-chemical parameters along with standard deviation at five sampling sites

Sites	pH	Temp.	DO	COD	TDS	BOD
S-1	7.61±0.54	23.3±2.37	6.48±0.92	23.38±9.37	135.8±35.23	6.908±2.44
S-2	7.37±0.49	23.8±2.44	5.13±1.26	50.61±33.3	326.4±119.27	9.39±2.88
S-3	7.38±0.41	23.8±2.51	4.26±1.71	48.59±13.0	346.62±119.57	9.81±2.73
S-4	8.26±0.48	25.8±3.06	0.15±0.10	182.52±90.0	2,606.04±1,354.25	167.76±92.8
S-5	8.61±0.56	26.6±3.6	0.106±0.07	661.37±280.1	3,505.01±1,892.98	223.95±116.6

All the values are in mg/l except for pH and temperature (in degrees Celsius)

Table 2 Correlation matrix among various physico-chemical parameters and heavy metals (significance level 0.05)

|	pH	Temperature	DO	COD	TDS	BOD	Pb	Ni	Cu	Zn	Cr
pH	1										
Temperature	0.952469	1									
DO	-0.8839	-0.96999	1								
COD	0.87731	0.882379	-0.76026	1							
TDS	0.97465	0.996475	-0.95606	0.888918	1						
BOD	0.982752	0.99209	-0.94914	0.881977	0.999016	1					
Pb	0.140317	-0.16106	0.271799	-0.09411	-0.07992	-0.03709	1				
Ni	0.863612	0.904206	-0.79068	0.982825	0.900847	0.890692	-0.1792	1			
Cu	0.956653	0.976229	-0.90005	0.962078	0.979937	0.975768	-0.1014	0.9643	1		
Zn	-0.53162	-0.58128	0.669483	-0.47596	-0.57553	-0.56776	0.272765	-0.38985	-0.5442	1	
Cr	0.940899	0.961971	-0.8765	0.977241	0.965073	0.959564	-0.11601	0.976325	0.997887	-0.5354	1

monsoon season, i.e. 12.42 mg/kg (Fig. 3e). At both the study areas, the concentration of chromium exceeded the Interim Sediment Quality Guidelines for the protection of aquatic life which was 37.3 mg/kg (Interim Freshwater sediment quality guidelines (ISQGs) et al. 1999).Chromium showed positive correlation with Ni ($r=0.976$) and Cu ($r=0.997$), whereas it was negatively correlated with Zn ($r=-0.535$) and Pb ($r=-0.116$).The presence of more dye and chrome plating units, i. e. small scale industries in Vatva industrial Estate and the direct discharge of effluent into the Kharicut canal might be the reason of high concentration of chromium in sediments at S-4 and S-5.

The concentration of copper at S-1, S-2 and S-3 ranged between 11.7 and 28.48 mg/kg in pre-monsoon, 4.33–20.85 mg/kg in monsoon and 12.87–23.98 mg/kg post-monsoon season, respectively. The values were lower than the prescribed guidelines of ISQGS (35.7 mg/kg), whereas the concentration of Cu at S-4 and S-5 exceeded the ISQGs values and varied between 101.88 and 239.57 mg/kg in pre-monsoon, 54.87–86.49 mg/kg in monsoon and 110.87–198.63 mg/kg in post-monsoon season, respectively (Fig. 3c). Copper exhibited positive correlation with Ni and Cr with $r=0.964$ and $r=0.997$, respectively.

Nickel is suspected to be essential trace elements for plants as well as for animals and used principally in its metallic form combined with other metals and nonmetals as alloys (Aboud and Nandini 2009). Nickel ranged between 5.71 and 15.58 mg/kg in pre-monsoon, 4.8 and 10.81 mg/kg in monsoon and 3.54 and 16.23 mg/kg at S-1, S-2 and S-3. At S-4 and S-5, it varied between 11.94 and 33.12, 8.58 and 17.66, and 9.2 and 20.81 mg/kg in pre-monsoon, monsoon and post-monsoon seasons, respectively. Metals such as chromium, copper, and nickel have interacted with organic matter in aqueous phase and settled to the bottom, resulting in a high concentration of these metals in the sediment (Abida et al. 2009).

Zinc was the second most abundant in sediments and its concentration ranged from 8.87 to 476.85 mg/kg at S-1, 36.37–451.06 mg/kg at S-2 and 20.66–56.52 mg/kg at S-3. In sediments of S-4 and S-5, the concentration of Zn ranged between 22.21 and 119.67 mg/kg. Zn showed higher concentration in post-monsoon season followed by pre-monsoon and monsoon season (Fig. 3d). However, the mean value of Zn was well within the stipulated guidelines of ISQGS (123 mg/kg). As S-1 is surrounded by many

Fig. 2 Seasonal variation heavy metal concentration in sediments at five sampling sites. **a** Seasonal variation in Pb (in parts per million). **b** Seasonal variation in Ni (in parts per million). **c** Seasonal variation in Cu (in parts per million). **d** Seasonal variation in Zn (in parts per million). **e** Seasonal variation in Cr (in parts per million)
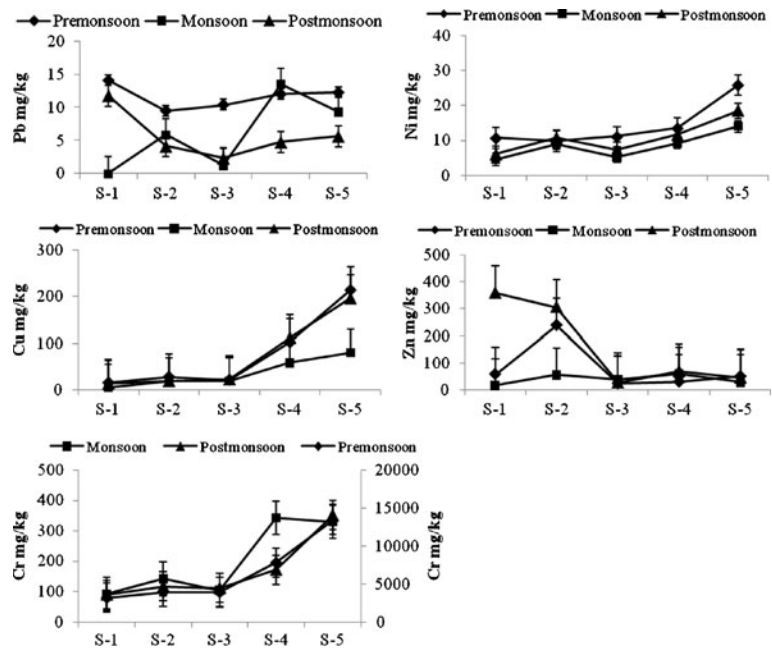

agricultural farms, the higher concentration of Zinc in sediment may be attributed to the presence of unused remains of zinc sulphate in fertilizers (Reza and Singh 2010). Zinc is positively correlated with Pb ($r=0.272$) and was negatively correlated with Cu, Cr and Ni with $r=-0.544$, -0.535 and -0.389 respectively.

The concentration of lead was found to be the lowest among all the heavy metals and was below detectable limit (BDL) in river sediment (Table 3). The maximum concentration observed was 16.96 mg/kg in monsoon at S-4 and S-5 while the lowest concentration observed was 1.67 mg/kg at S-3 in post-monsoon season (Fig. 3a). The values obtained were below ISQGs value at all five sites (35.0 mg/kg). The lower values of lead might be attributed to less solubility of Pb-containing minerals in natural water (Venugopal et al. 2009). Lead also showed negative correlation with all other heavy metals studied (PbxNi: $r=-0.179$, PbxCu: $r=-0.101$,

Fig. 3 Seasonal variation in heavy metal concentration in water at five sampling sites. **a** Seasonal variation in Pb (in parts per million). **b** Seasonal variation in Ni (in parts per million). **c** Seasonal variation in Cu (in parts per million). **d** Seasonal variation in Zn (in parts per million). **e** Seasonal variation in Cr (in parts per million)
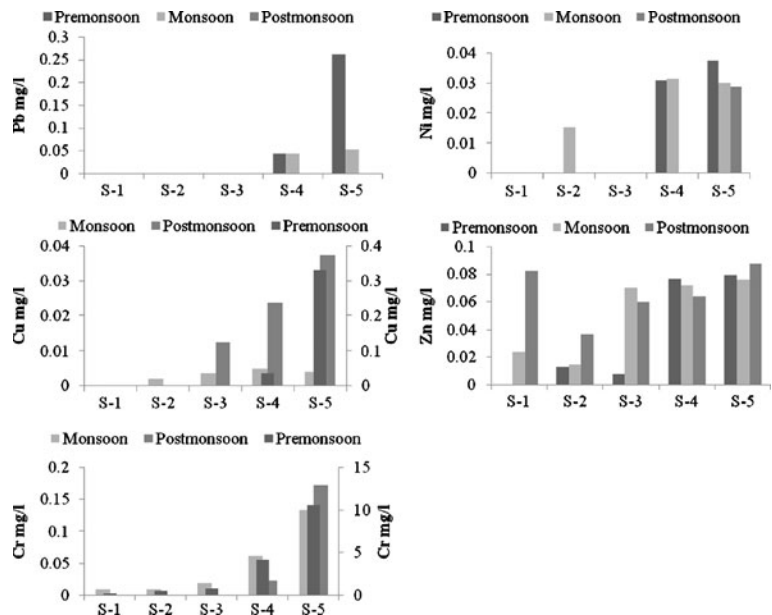
Table 3 Heavy metal concentration in water and sediments of Sabarmati River and Kharicut Canal during different seasons

Metals	Pre-monsoon				Monsoon				Post-monsoon			
	April		May		August		September		October		January	
	SR	KC	SR	KC	SR	KC	SR	KC	SR	KC	SR	KC
Dissolve (mg/l)												
Pb	BDL	0.047–0.0618	BDL	0.042–0.461	BDL	0.042–0.051	BDL	0.043–0.548	BDL	BDL	BDL	BDL
Ni	BDL	0.034–0.0357	BDL	0.027–0.039	BDL	0–0.0245	BDL	0.031–0.036	BDL	BDL	BDL	0–0.289
Cr	0.46–1.49	5.17–18.60	0.076–0.377	1.58–3.143	0.010–0.031	0.028–0.093	0.008	0.095–0.175	BDL	0–0.0357	BDL	0.0237–0.0309
Zn	0.008–0.013	0.076–0.078	BDL	0.072–0.0802	0.014–0.113	0.085–0.086	0.0274	0.058–0.065	0.036–0.155	0.070–0.11	0.009–0.030	0.014–0.103
Cu	BDL	0.036–0.565	BDL	0.036–0.097	0.0131	0.013–0.0145	0.0242	0.015–0.024	0–0.0125	0.023–0.036	BDL	0.024–0.0386
Sediments (mg/kg)												
Pb	9.91–11.01	12.25–13.05	8.36–11.25	11.87–11.60	BDL	9.04–9.99	0–5.82	9.52–16.96	1.30–2.68	3.21–7.91	1.66–4.23	1.63–8.06
Ni	5.71–12.36	15.03–33.12	7.19–15.58	11.94–18.58	4.34–10.81	8.58–17.66	4.8–8.04	9.98–6.08	3.54–12.64	9.20–16.23	8.53–8.92	14.10–20.81
Cr	2,077.6–3,930.7	8,805.5–16,838.0	2,530.5–4,719.2	6,822.2–9,908.7	8.81–14.51	22.48–38.07	10.92–13.75	21.58–45.66	6.50–20.32	16.10–25.59	12.42–14.67	18.75–45.17
Zn	36.37–54.74	40.90–75.07	42.42–65.77	22.21–28.32	8.87–65.94	37.24–45.66	20.66–46.35	23.41–73.85	422.5–476.8	24.09–30.36	163.4–334.9	65.78–119.67
Cu	11.7–28.4	101.88–189.46	20.51–28.48	103.97–239.57	4.33–18.54	54.87–72.57	5.46–20.85	61.37–86.49	15.98–22.986	110.87–198.63	12.87–23.98	113.28–193.85

SR Sabarmati River; *KC* Kharicut canal

PbxZn: $r=0.272$, PbxCr: $r=-0.116$). The mean concentration of heavy metals observed in the sequence: Cr > Zn > Cu > Ni > Pb.

In water samples also chromium was the most abundant element and the concentration varied between 0.008 and 1.49 mg/l at S-1, S-2 and S-3. However, in post-monsoon season, the values were BDL whereas at S-4 and S-5 the values registered were 1.58–18.60, 0.028–0.175 and 0.023–0.035 mg/l in pre-monsoon, monsoon and post-monsoon season, respectively (Fig. 3e). The values exceeded CPCB standard (0.05 mg/l, Maiti 2001). Chromium and its salts are used in the leather tanning industry, pigments and paints, in fungicides, the ceramic and glass industry and in chrome alloy and chromium metal production (WHO 2004).

The seasonal variation in Cu is depicted in Fig. 3c. The concentration of copper was the highest at S-5, i.e. 0.566 mg/l and the lowest was recorded at S-3, i.e. 0.012 mg/l. The mean concentrations obtained were lower than the prescribed CPCB standard (1.5 mg/l). Low level of copper in the surface water could be due to the adsorption of Cu on the particulate matter and consequent settlement to the bottom (Sankar et al. 2010).

Zinc and copper are generally good indicators of anthropogenic inputs. Zinc is used in galvanizing steel and iron product. Zinc oxide is used in rubber manufacturing industries as an additive to activate vulcanization process. Zinc carbamates are used as pesticides (Aboud and Nandini 2009). The concentration of Zinc at S-1, S-2 and S-3 fluctuated between 0.008 and 0.155 mg/l except for the month of May in which it was not detectable (Fig. 3d), whereas in canal water it ranged between 0.0142 and 0.103 mg/l and was lower than standard values of CPCB (15 mg/l). The other two heavy metals, i.e. lead and nickel were BDL at S-1, S-2 and S-3 in three seasons. However, S-4 and S-5 showed noticeable concentration of Pb and Ni. It varied between 0.042 and 0.061 mg/l at S-4 and 0.024 and 0.039 mg/l at S-5, while in post-monsoon season concentration was BDL in case of both heavy metals (Fig. 3a, b).

The concentration of heavy metals varied seasonally and showed highest concentration in pre-monsoon season followed by monsoon and post-monsoon season. A similar trend was observed by Lohani et al. (2008) in Gomti River (pre-monsoon > monsoon > post-monsoon). Table 4 depicts the values of heavy metals recorded for various Indian river waters along with the present data. It was found that the mean concentrations of Cu, Zn and Cr were higher in Sabarmati

Table 4 Comparison of dissolved metal concentration with other Indian Rivers

River	Heavy metals (µg/L)				
	Pb	Ni	Cu	Zn	Cr
Subarnrekha[a]	19.13	15.75	15.88	23.0	1.13
Hindon[a]	37.0	24.0	6.6	58.0	15.0
Baitarani[a]	3.45	3.9	3.45	272.3	9.6
Mahanadi[a]	2.68	7.2	5.9	11.0	9.8
Achankovil[a]	72	–	224	415	–
Koel[a]	1.67	24.78	6.67	31.56	10.89
Damodar[a]	–	–	3,950	–	11,550
Ganga[a]	120	140	10	60	–
Gomti[b]	27.5	–	–	–	124.5
Sabarmati[c]	BDL	BDL	12.9	47.39	342.13
KC[c]	100.41	32.2	77.11	74.5	2,660.4

[a] Ref Reza and Singh (2010)

[b] Ref Lohani et al. (2008)

[c] Present study

river and Kharicut canal than other rivers. Hence, it can be said that the river Sabarmati and Kharicut canal received significant amount of heavy metal contamination. However, Ganga and Damodar rivers registered exceptionally high values for all heavy metals.

Contamination factor and contamination degree

To determine an anthropogenic influence on the fresh water ecosystems, the heavy metal contamination factor was calculated as the ratio of concentrations from upper most sediment layer to the average shale values. The average shale values for Pb 20 mg/kg, Ni 68 mg/kg, Cr 90 mg/kg, Zn 95 mg/kg and Cu 45 mg/kg (Turekian and Wedepohl 1961) are commonly used as background values in sediment studies (Kucuksezgin et al. 2008; Saha et al. 2001; Datta and Subramanian 1998).

$$C_f = \frac{\text{Concentration of metal in sediment}}{\text{Background value of metal}}$$

$$PLI = \sqrt[n]{\text{Product of } n \text{ number of } C_f \text{ values}}$$

where

C_f Contamination factor
n Number of heavy metals

The degree of contamination (C_d) was defined as the sum of all contamination factors, and the values are

given in Table 3. The following terminology is suggested for describing the contamination factor (C_f values, Hakanson 1980): $C_f <1$—low contamination factor, $1\leq C_f<3$—moderate contamination factor; $3\leq C_f<6$—considerable contamination factor and $C_f >6$—very high contamination factor. The following terminology is adopted to describe the degree of contamination (C_d values) for heavy metals: $C_d <6$—low degree of contamination, $6\leq C_d<12$—moderate degree of contamination, $12\leq C_d<24$—considerable degree of contamination and $C_d \geq24$—very high degree of contamination indicating serious anthropogenic pollution.

The elevated level of trace metals especially in the sediments can be a good indication of man-induced pollution and high levels of heavy metals and often can be attributed to anthropogenic influences, rather than natural enrichment of the sediment by geological weathering (Davies et al. 1991). Table 5 represents the values of contamination factor and contamination degree for the five sampling sites. Maximum values of contamination factor for heavy metal (except for Zn) were noticed in the sediments of sites 4 and 5. The degree of contamination is also highest at S-4 and S-5 with values 32.25 and 54.52, respectively, which indicates serious anthropogenic pollution. Whereas at three sites of river Sabarmati, the values obtained ranged from 12 to 24 which indicates considerable degree of contamination. This leads to the assumption that the work on Sabarmati River Front Development has created considerable anthropogenic pressure on river ecosystem. Pollution load index (PLI) shows the magnitude and extent of the heavy metals deposition in the bed sediment of the study area over a long period of time. The values of PLI at S-1, S-2 and S-3 ranged between 0.75 and 0.815 whereas S-4 and S-5 showed values of 1.169 and 1.54, respectively. In this

Table 5 Metal contamination factor (C_f), degree of contamination (C_d) and pollution load index (PLI) for five sampling sites

Site	C_f					C_d	PLI
	Pb	Ni	Cr	Zn	Cu		
1	0.514	0.103	11.90	1.527	0.261	14.30	0.758
2	0.290	0.146	12.08	1.41	0.496	14.42	0.814
3	0.267	0.115	14.69	1.674	0.473	17.21	0.815
4	0.502	0.168	29.12	0.441	2.021	32.25	1.169
5	0.453	0.234	49.76	0.456	3.62	54.52	1.54

case, the results suggest that the sediments in Kharicut canal are deposited with more heavy metal accumulation than those in Sabarmati river sediments. The values of PLI clearly indicate the high pollution load from upstream to downstream (Table 5).

From the above study, it is clear that surface sediments show high degree of heavy metals contamination than river waters. In water, the heavy metals showed following trend of seasonal variation: pre-monsoon > monsoon > post-monsoon. The values of PLI increased in the downstream of river. Site 3 showed the highest degree of contamination among three river sites as it received domestic and sewage effluent, this also indicates high anthropogenic pressure on river ecosystem. The River Front Development activity also has a profound impact on distribution of heavy metals in river. However, the highest metal concentrations were generally detected at S-4 and S-5 along with highest values of C_d and PLI. These results showed that the industrial effluent discharge is responsible for the deposition of heavy metals in sediments and water of Kharicut canal.

Conclusion

The present study revealed that the C_d and PLI values gradually increased from upstream to downstream. Heavy metals such as Zn, Pb and Ni were observed within the prescribed limits whereas values of copper exceeded in sediment samples. Among all heavy metals, the Cr content was the highest which varied seasonally with maximum concentration during pre-monsoon season. Industries like dye, chrome plating, textile, tannin, leather, paints, etc. are major threats for high level of chromium in water as well as sediment samples. There is need to reduce industrial inputs into the canal otherwise the local food web complexes might be at highest risk of induced heavy metals contamination.

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