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Full Length Article

Evaluation of Arsenic Toxicity to Biota in River Ravi (Pakistan) Aquatic Ecosystem

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ABSTRACT

The extent of arsenic (As) toxicity to water, bed sediments, plankton and fish in the river Ravi at three main public fishing sites viz. Shahdera bridge, Baloki headworks and Sidhnai barrage were evaluated. Among these three public fishing sites, Sahahdara bridge had significantly higher As toxicity of water, sediments and planktonic biota attributed to the bulk discharges of untreated effluents, originating from adjacent industrial areas and urban runoffs through various small tributaries. As toxicity of water at all three sites was generally low but the contamination levels in both sediments and biota were significantly higher. The uptake and accumulation of As by the sediments and plankton were dependent upon metallic toxicity of water indicating their role as metallic pollution indicators of the river ecosystem. The fish at Shahdera bridge had significantly higher As in their body organs than those collected from the both Baloki headworks and Sidhnai barrage. A significant enrichment of As in fish body organs had direct dependence on the As toxicity of water, sediments and plankton showing bio-accumulation and biological magnification of this toxicant up to the food chain of river ecosystem. All the organs of both herbi–and carnivorous fish species showed significantly variable accumulation of As that followed the sequence: liver > kidney > gills > intestine > reproductive organs > scale > skin > fins > bones > muscles > fats. The toxicity of As in the food chain of river Ravi was in the order: sediments> plankton> water> fish tissues. As uptake in all the body organs, except fats, of herbivorous cyprinids showed significantly positive dependence on the As toxicity of plankton, while carnivore fish showed their dependence to bio-accumulate As dependent upon the toxicity of both sediments and plankton. © 2011 Friends Science Publishers

Key Words: River Ravi; Arsenic; Sediments; Plankton; Fish

INTRODUCTION

Water bodies are the important natural resources to meet the diversified human demands. River pollution is commonly associated with the discharge of effluents from industries and city sewage. The dilemma of water pollution is severe in many countries but is essentially the same throughout the world. However, the degree and pace of water pollution in the last few decades has been increased significantly due to rapid industrialization and urbanization in the province of Punjab, Pakistan (Rauf *et al*., 2009). Therefore, aquatic pollution has become more serious due to their consequences on the human health and sustainability of aquatic habitats (Anazawa *et al*., 2004). In aquatic ecosystem, the sediments represent an important sink for trace metals and their metallic ion toxicity would become several times higher than in the overlying water (Singh *et al*., 2002). Therefore, contaminated sediments pose a significant risk to detritus feeding benthic organisms and plankton and may also act as a long-term source of metallic ion pollution to higher trophic levels (Eimers *et al*., 2001). In the aquatic ecosystems, fish and plankton are considered as the important indicators of heavy metal enrichment (Novelli *et al*., 1998; Gernhofer *et al*., 2001).

In nature arsenic (As) can exist in both inorganic as well as organic forms. As [As^{3+}] and arsenate [As^{5+}] are the inorganic, while monomethyl arsenic acid, dimethyl arsenic acid, arsenobetaine, arsenocholine and different arsenolipids and arsenosugars may be the organic forms of As (Elci *et al*., 2008). As is a naturally occurring metalloid that is present in water, soil and air (Duker *et al*., 2005), while volcanoes act as a major natural source of As for its release into the environment (Smedley & Kinniburgh, 2002). As is also used as a weed killer and hence contaminating the natural water through runoffs. In natural aquatic habitats, the toxicity of various metals has been studied by assessing their contamination in water, plankton and sediments (Javed, 2003).

In the age of industrialization, improper management of the industrial runoff water is aggravating the menace of environmental pollution. The toxicity of heavy metals has been realized as a major threat to the aquatic ecosystem, where runoff water is usually discharged. In Pakistan, River Ravi is worst hit with such an activity. The present study was conducted to assess the As toxicity gradient and multivariate relationships among water, sediments, plankton

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and fish in the river Ravi aquatic ecosystem at three main public fishing sites viz. Shahdera bridge, Baloki headworks and Sidhnai barrage.

MATERIALS AND METHODS

Water, sediments, plankton and fish samples were collected, on monthly basis, from the three main public fishing sites viz. Shahdera bridge, Baloki headworks and Sidhnai barrage during one year study period (May, 2009 to June, 2010). Each station was divided into two sub-stations viz. (i) upstream and (ii) downstream for the collection of water, sediments, plankton and fish by following the proportionate sampling procedure (Steel *et al*., 1996).

Water samples were collected from just below the surface and column (maximum 1 m below the surface) by using Kemmerer. Water samples were collected in quartz bottles for the determination of As and were immediately placed in ice bags and transported to the laboratory for analysis. River bed sediment samples consisting of approximately 500 g of surface layer were collected with the help of a PVC pipe (5 cm) pressed with pressure through the water column to obtain the sediment layer of about 0.25 m. Polyethylene scoops and cans were used for sampling and storage. The samples were put in ice bags during transportation to the laboratory and stored in a deep freeze unit until the drying procedure and further analyses. The bed sediment samples were dried at 120^{o}C over night in the oven. In order to minimize the grain size distributions, the dried samples were sieved. Dry weights of planktonic biomass were accomplished by evaporation method (Javed, 1988). Fish samples were collected on monthly basis from the three sites viz. Shahdera bridge (Lahore), Baloki headworks and Sidhnai barrage. Five fish (n=5) belonging to herbivore fish species viz. *Catla catla*, *Labeo rohita* and *Cirrhina mrigala* and carnivorous fish species viz. *Rita rita*, *Mystus sperata* and *Wallago attu* were sampled randomly for analyses. Sampled fish were dissected to obtain the samples of fish organs viz. gills, liver, kidney, intestine, reproductive organs, skin, muscle, fins, scales, bones and fats. After wet digestion, samples of water, sediments, plankton and fish were analyzed for As directly in acidified filtrates by Atomic Absorption Spectrometry (Perkin Elmer, AAnalyst 400) by following method # 3500-As B of APHA (1998).

Data collected on water, plankton, sediments and fish were analyzed by following Steel *et al*. (1996). Analysis of variance and Tukey's/Student Newman-Keul tests were applied to find-out statistical differences among various parameters. Correlation coefficients among various variables were obtained to find-out relationships for the flow pattern of As in the aquatic ecosystem.

RESULTS

As in water: The mean monthly concentrations of As in river water at three sampling stations were significantly variable at $p<0.05$ during various months of the study period (May, 2009 to June, 2010). The mean As concentrations at Shahdera bridge, Baloki headworks and Sidhnai barrage were the maximum (21.47, 17.27 & 19.20 mg L^{-1}, respectively) during January but minimum as (9.84, 7.88 & 9.67 mg L^{-1}, respectively) during May. Regarding year-round mean As concentrations, the water at Shahdera bridge was significantly more contaminated with As than that of Sidhnai barrage and Baloki headworks with the mean concentrations of 15.10, 14.04 and 13.15 mg L^{-1}, respectively. Mean As concentration for three sampling stations was maximum as 19.31 mg L^{-1} during January but minimum as 9.13 mg L^{-1} during the month of May (Table I).

As in bed sediments: As contaminations in the river bed sediments fluctuated significantly among the three sampling stations with the mean annual higher contamination level of 34.70 µg g^{-1} at Shahdera bridge, followed by that at Sidhnai barrage (29.00 µg g^{-1}) and Baloki headworks (24.92 µg g^{-1}). The seasonal effect on the fluctuations in the As toxicity was statistically significant ($p<0.05$). At Shahdera bridge, the As toxicity in bed sediments varied significantly within the range of 22.15-48.20 µg g^{-1} (June-November), while that at Baloki headworks, it fluctuated between 34.62 µg g^{-1} (January) and 13.21 µg g^{-1} (September). At Sidhnai barrage, As toxicity in sediments fluctuated significantly within the maximum and minimum mean concentrations of 37.79 and 19.19 µg g^{-1} recorded during the months of January and June, respectively. The sediments at Shahdera Bridge exhibited significantly higher As toxicity than that at Baloki headworks and Sidhnai barrage during the whole study period (May, 2009 to June, 2010). The maximum and minimum mean As levels of 38.22 and 19.37 µg g^{-1}, respectively were recoded during the months of January and May, respectively as far as overall mean As concentrations in the bed sediments of three sampling stations were concerned (Table II).

As in plankton: The planktonic biota collected during 12 months of the study period (May, 2009 to June, 2010) showed significant variations with As concentrations in the river Ravi. The As contamination in the planktronic biomass at all the stations were minimum during June. Plantonic As concentrations were higher as 36.53, 28.65 and 31.42 µg g^{-1} at Shahdera bridge, Baloki headworks and Sidhnai barrage during the months of January, December and January, respectively. Regarding overall As toxicity indices of planktonic population at three sampling sites, the highest toxicity (31.62 µg g^{-1}) was recorded during the month of January, while it was minimum (16.84 µg g^{-1}) during June. The plankton collected from the Shahdera bridge had significantly higher mean As (28.43 µg g^{-1}), followed by the toxicity levels of 25.42 and 22.63 µg g^{-1} observed at Sidhnai barrage and Baloki headworks, respectively (Table III).

As in the fish: Fish organs viz. gills, liver, kidney, intestine, reproductive organs, skin, muscle, fins, scales, bones and fats showed significantly variable ability to accumulate As ($p<0.05$). The herbivorous cyprinids and carnivore fish

Table I: Arsenic concentration (mg L^{-1}) in the water of river Ravi

Months	Sampling Stations			Overall mean concentrations for three Sampling Stations
	Shahdera bridge	Baloki headworks	Sidhnai barrage	
June, 2009	14.58±0.07 h	13.45±0.09 g	14.36±0.08 d	14.13±0.60 g
July	14.70±0.08 g	13.66±0.10 f	14.39±0.06 d	14.25±0.53 f
August	14.83±0.06 f	13.68±0.12 ef	14.53±0.07 d	14.35±0.60 e
September	15.03±0.09 e	14.87±0.02 d	14.95±0.02 c	14.95±0.08 d
October	13.63±0.05 i	11.41±0.07 h	12.34±0.07 f	12.46±1.11 i
November	18.34±0.06 b	16.20±0.05 b	17.08±0.04 b	17.21±1.08 b
December	15.21±0.05 d	13.37±0.05 g	13.17±0.05 e	13.92±1.12 h
January	21.47±0.04 a	17.27±0.05 a	19.20±0.05 a	19.31±2.10 a
February	17.26±0.07 c	15.92±0.07 c	17.14±0.04 b	16.77±0.74 c
March	13.74±0.06 i	10.54±0.07 i	11.43±0.09 g	11.90±1.65 j
April	12.55±0.05 k	9.51±0.11 j	10.21±0.06 h	10.76±1.59 k
May, 2010	9.84±0.04 l	7.88±0.07 k	9.67±0.06 i	9.13±1.08 l
(Single column means are nonsignificant at p< 0.05)				
Sampling Stations	**15.10±2.93 a**	**13.15±2.84 c**	**14.04±2.88 b**	

Table II: As concentrations (μg g^{-1}) in the bed sediments of the river Ravi

Months	Sampling Stations			Overall mean concentrations for three Sampling Stations
	Shahdera bridge	Baloki headworks	Sidhnai barrage	
June, 2009	22.15±0.10 k	17.86±0.08 k	19.19±0.05 j	19.73±2.20 j
July	25.24±0.05 i	18.72±0.05 j	21.34±0.06 h	21.77±3.28 i
August	27.51±0.09 h	20.88±0.06 i	23.52±0.05 g	23.97±3.34 h
September	24.35±0.10 j	13.21±0.05 l	20.55±0.07 i	19.37±5.66 j
October	42.98±4.10 b	23.57±0.09 h	27.72±0.08 f	31.42±10.22 f
November	48.20±0.10 a	26.83±0.06 f	30.23±0.12 e	35.09±11.48 c
December	35.42±0.08 f	28.20±0.08 d	33.28±0.07 c	32.30±3.71 e
January	42.26±0.10 b	34.62±0.09 a	37.79±0.08 a	38.22± 3.84 a
February	40.20±0.13 c	32.20±0.13 b	35.18±0.06 b	35.86±4.04 b
March	37.56±0.09 d	27.30±0.11 ef	31.21±0.05 d	32.02±5.18 e
April	34.14±0.10 g	25.35±0.08 g	33.14±0.09 c	30.88±4.81 g
May, 2010	36.39±0.08 e	30.29±0.08 c	34.86±0.05 b	33.85±3.17 d
(Single column means are nonsignificant at p< 0.05)				
Sampling Stations	**34.70±8.29 a**	**24.92±6.32 c**	**29.00±6.39 b**	

Table III: As concentrations (μg g^{-1}) in the plankton of the river Ravi

Months	Sampling Stations			Overall mean concentrations for three Sampling Stations
	Shahdera bridge	Baloki headworks	Sidhnai barrage	
June, 2009	18.52±0.05 l	15.71±0.07 j	16.30±0.06 l	16.84±1.48 l
July	22.71±0.09 j	17.88±0.06 i	19.48±0.05 k	20.02±2.46 j
August	24.24±0.07 i	18.54±0.06 h	21.24±0.06 h	21.34±2.85 i
September	21.52±0.08 k	17.78±0.05 i	20.27±0.07 j	19.86±1.90 k
October	28.68±0.07 g	21.89±0.05 f	26.41±0.06 f	25.66±3.46 g
November	32.89±0.07 d	27.20±0.06 b	30.84±0.06 b	30.31±2.88 b
December	33.32±0.07 c	28.65±0.08 a	28.18±0.06 d	30.05±2.84 c
January	36.53±0.08 a	26.90±0.06 c	31.42±0.07 a	31.62±4.82 a
February	31.67±0.06 e	27.20±0.06 b	30.74±0.06 b	29.87±2.36 d
March	34.20±0.08 b	22.70±0.07 e	27.22±0.37 e	28.04±5.79 f
April	30.25±0.06 f	25.88±0.07 d	29.22±0.05 c	28.45±2.28 e
May, 2010	26.58±0.05 h	21.19±0.05 g	23.67±0.06 g	23.81±2.70 h
(Single column means are nonsignificant at p< 0.05)				
Sampling Stations	**28.43±5.69 a**	**22.63±4.47 c**	**25.42±5.09 b**	

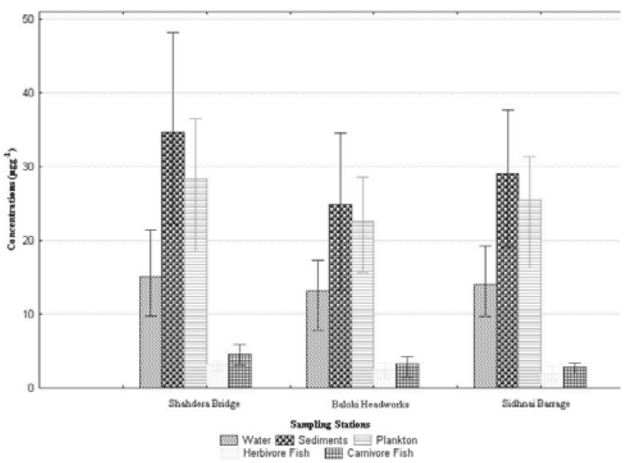
species exhibited significantly different abilities to accumulate As in their body organs. All the six species of fish had As toxicity levels in the order: *W. attu*> *R. rita*> *M. sperata*> *C. mrigala*> *L. rohita*> *C. catla*. The environment at Shahdera bridge, Baloki headworks and Sidhnai barrage caused significant amassing of As in the body organs of fish. The maximum mean As concentration of 4.01 μg g^{-1} was recorded in the body organs of W. *attu* but minimum one (2.12 μg g^{-1}) in the body of herbivorous fish, *C. catla*. The fish were significantly more contaminated with As at Shahdera bridge (3.87 μg g^{-1}), followed by the contamination levels of 2.79 and 2.47 μg g^{-1} in the fish samples taken from Baloki headworks and Sidhnai barrage, respectively. All the six fish species accumulated significantly higher As concentration in their liver, followed by that in kidney with the mean As concentration of 3.82 and 3.72 μg g^{-1}, respectively. However, accumulation of As remained significantly lowest in fish muscle and fats (Table IV).

Table IV: Arsenic concentrations (µg g^{-1}) in the fish body organs

Organs	Arsenic concentrations (µg g^{-1})	Species	Arsenic concentrations (µg g^{-1})	Sampling stations	Arsenic concentrations (µg g^{-1})
Gills	3.37±0.99 d	*Catla catla*	2.12±0.59 f	Shahdera bridge	3.87±0.13 a
Liver	3.82±0.98 a	*Labeo rohita*	2.49±0.43 e	Bbloki headworks	2.79±0.17 b
Kidney	3.72±0.99 b	*Cirrhina mrigala*	2.93±0.31 d	Sidhnai Barrage	2.47±0.09 c
Intestine	3.48±0.99 c	*Rita rita*	3.53±0.76 b	**Means**	**3.04±0.73**
Reproductive organs	3.38±1.00 d	*Mystus sperata*	3.19±0.67 c		
Skin	3.19±0.96 e	*Wallago attu*	4.01±0.84 a		
Muscle	2.26±0.77 h	**Means**	**3.04±0.69**		
Fins	3.05±1.08 f				
Scales	3.07±0.95 f				
Bones	2.62±0.76 g				
Fats	1.50±0.75 i				
Means	**3.04±0.68**				

Single column means are non-significant at $p< 0.05$

Fig. 1: Flow patterns of arsenic in the river Ravi aquatic ecosystem



Regression analyses showed possible relationships among water, sediments and plankton for the uptake and accumulation of As in the body organs of herbi- and carnivore fish species collected from the three sampling stations of the river Ravi. As uptake in all the body organs, except fats of herbivorous cyprinids showed significantly positive dependence on the As toxicity of plankton, while carnivore fish showed their dependence to bio-accumulate As dependent upon the toxicity of both sediments and plankton. However, the contamination level of As in water showed no significant contribution towards its bio-accumulation in fish body (Table V & VI).

Fig. 1 shows the flow patterns of As in the river Ravi aquatic ecosystem. The graphic pattern showed that As discharged through industrial effluents and domestic sewage in the river water caused significant escalation of As in the river bed sediments and planktonic biota that has resulted in significant bio-accumulation of As in the body organs of herbivorous cyprinids. However, significantly higher As found in the bodies of carnivorous fish species depicts biomagnification of As in the food chain.

DISCUSSION

The rapid industrial growth in the areas adjacent to the river Ravi, during the last three decades, has resulted in the river pollution due to bulk discharges of untreated industrial wastes, domestic sewage and runoff from agriculture fields (Rauf & Javed, 2007). The present investigation revealed that the mean annual toxicity of As in the river water at three main public fishing sites viz. Shahdera bridge, Baloki headworks and Sidhnai barrage fluctuated greatly. The water quality is regarded as the major controlling factor of human health and diseases in animals (Rashid, 2001). Significantly higher As toxicity at Shahdera bridge was attributed to the bulk discharges of untreated effluents, originated from adjacent chemical industries and agriculture runoff discharged through various small tributaries into the river Ravi. Javed and Hayat (1999) reported significant contribution of tributaries viz. Mahmood Booti nulla, Hudiara nulla, Shadbagh nulla, Farrukhabad nulla, Munshi hospital nulla and Taj company nulla towards metallic toxicity of river Ravi. Rauf (2009) reported significant effects of these tributaries towards copper, cobalt, cadmium and chromium contamination of Shahdera bridge and Baloki headworks.

The present investigation revealed that uptake and accumulation of As by the sediments and plankton was dependent, positively and significantly, upon As toxicity of water. As toxicity is caused due to binding of As to the thiol groups of proteins and inhibition of enzymes (Sari & Tuzen, 2009). The chemicals discharged into the aquatic bodies are ultimately adsorbed by the sediments that would become a sink and source of pollutants/pollution. The heavy metals that are released into the aquatic habitats are quickly absorbed by the plankton (Wang & Guo, 2000) and could also be adsorbed by the suspended particles that ultimately settle down and become part of the bed sediments. Heavy metals present in the bed sediments are mobilized in the aquatic components due to significant changes in physico-chemical characteristics of water (Kelderman *et al*., 2000) and are biologically magnified in the fish and human body through aquatic food chain/web as observed

Table V: Relationships among water, plankton and sediments for the uptake and accumulation of arsenic in the body organs of herbivore fish collected from the river Ravi

	(y)	Final-Step Equations	r/MR	R^2
Herbivore fish	Gills	=0.08+0.10 (As in plankton) (0.018) $^{p<0.001}$	0.7058	0.4982
	liver	=0.42+0.11 (As in plankton) (0.019) $^{p<0.001}$	0.6951	0.4831
	Kidney	=0.37+0.11 (As in plankton) (0.019) $^{p<0.001}$	0.6940	0.4816
	Intestine	=0.10+0.12 (As in plankton) (0.018) $^{p<0.001}$	0.7374	0.5438
	Reproductive Organs	= – 0.12+0.11 (As in plankton) (0.020) $^{p<0.001}$	0.7078	0.5010
	Skin	= – 0.33+0.11 (plankton) (0.26) $^{p<0.001}$	0.7285	0.5307
	Muscles	= –0.67+0.10 (As in plankton) (0.22) $^{p<0.001}$	0.7565	0.5722
	Fins	= –0.52+0.12 (As in plankton) (0.020) $^{p<0.001}$	0.7051	0.4972
	Scales	= –0.43+0.12 (As in plankton) (0.017) $^{p<0.001}$	0.7519	0.5654
	Bones	= –0.60+0.11 (As in plankton) (0.016) $^{p<0.001}$	0.7470	0.5580
	Fats	= –0.49+0.06 (As in sediments) (0.996) $^{p<0.001}$	0.6927	0.4798

Table VI: Relationships among water, plankton and sediments for the uptake and accumulation of arsenic in the body organs of carnivore fish collected from the river Ravi

	(y)	Final-Step Equations	r/MR	R^2
Carnivore fish	Gills	= 0.44 + 0.08 (As in sediments) + 0.10 (As in water) (0.018) $^{p<0.001}$ (0.048) $^{N.S.}$	0.6798	0.4621
	liver	= 2.03 + 0.08 (As in sediments) (0.018) $^{p<0.001}$	0.6077	0.3693
	Kidney	= 0.65 + 0.08 (As in sediments) + 0.01(As in water) (0.018) $^{p<0.001}$ (0.05) $^{N.S.}$	0.6732	0.4532
	Intestine	= 0.69+ 0.07 (As in sediments) + 0.09(As in water) (0.018) $^{p<0.001}$ (0.05) $^{N.S.}$	0.6497	0.4221
	Reproductive Organs	= 1.34 + 0.04 (As in plankton) + 0.05 (As in sediments) (0.022) $^{N.S.}$ (0.022) $^{p<0.001}$	0.6309	0.3980
	Skin	= 1.27 + 0.40 (As in plankton) + 0.50 (As in sediments) (0.022) $^{N.S.}$ (0.022) $^{p<0.05}$	0.6176	0.3814
	Muscles	= 0.91 + 0.06 (As in sediments) (0.015) $^{p<0.001}$	0.5728	0.3281
	Fins	= 1.48 + 0.08 (As in sediments) (0.018) $^{p<0.001}$	0.5744	0.3300
	Scales	= 1.75 + 0.07 (As in sediments) (0.019) $^{p<0.01}$	0.5095	0.2596
	Bones	= 0.98 + 0.04 (As in plankton) + 0.07 (As in water) (0.015) $^{p<0.01}$ (0.041) $^{N.S.}$	0.5455	0.2976
	Fats	= – 1.67 + 0.08 (As in sediments) + 0.08(As in water) (0.016) $^{p<0.001}$ (0.045) $^{N.S.}$	0.7117	0.5065

r = Correlation co-efficient; R^2 = Coefficient of determination

during present investigation. The As contamination levels of sediments and plankton are indicative of their role as bio-indicator of the metallic pollutions in the river Ravi ecosystem due to their persistent ability to remove metals from the water, accumulate and store them over a long period of time even at low concentrations of As in the water. Javed and Hayat (1996) reported that different genera of algae can act as indicator in appraising and estimating aquatic pollution with heavy metals. Significant correlation between the metallic toxicity of planktonic biota and water demonstrated the capability of plankton to concentrate heavy metals from aquatic environments. Akan *et al.* (2010) determined the extent of As, Co, Zn, Mo, Cd, Ni, Mn, Fe, Pb and Cr contamination of Ngada river.

The As toxicity increased significantly with increasing sediment depth, indicating age-long accumulation of heavy metals due to anthropogenic sources (Singh *et al.*, 2002). The escalated levels of As in the bed sediments at three sampling stations of the river Ravi beyond the permissible limits indicate the failure of detoxification ability of sediments in the river Ravi due to continuous influx of heavy metals discharged through various tributaries. The toxicity of As in water, sediments and plankton was variable at all the three sampling sites. River Ravi bed sediments showed an important sink for metallic ion toxicity causing the contamination of As significantly higher than that of overlying water as observed during this investigation (Singh *et al*., 2002). The metals adsorbed by the sediments become a significant danger to plankton that would become a long-term source of metallic toxicity to the higher tropic levels (Eimers *et al*., 2001). In the body organs of fish species viz. *C. catla*, *L. rohita*, *C. mrigala*, *R. rita*, *M. sperata* and *W. attu*, the accumulation of As was significantly higher in liver than in the other organs. Studies conducted on *Liza abu* have shown that heavy metals are mainly accumulated in metabolically active organs such as liver that stores metals to detoxify by producing metallothioneins (Sunlu *et al*., 2001). In this study, all the organs of fish species showed variable accumulation of metals with the sequence of liver > kidney > gills > intestine > reproductive organ > scales > fins > bones > muscle > fats. Significant variations in metallic ion concentrations in various organs was attributed to the differences in physiological functions of different organs in fish body (Storelli *et al*., 2006). Fish liver appeared as a target tissue/organ to accumulate As in fish body (Javed, 2003).

In conclusion, the escalation of As toxicity caused undesirable changes in the river ecosystem that in turn affected, directly or indirectly the ecological balance of the river Ravi. Therefore, the present extent of As pollution in the river Ravi has become a serious issue due to the ability of this metal to persist in the aquatic environment for a long period of time, bio-accumulation and biomagnification in the aquatic food web.

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