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METAL TOXICITY OF WATER IN A STRETCH OF RIVER RAVI FROM SHAHDERA TO BALOKI HEADWORKS

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Metal ion toxicity of the River Ravi stretch, from Shahdera to Baloki headworks, was studied. The river water showed considerable variation for the concentration of heavy metals due to variable discharges of untreated industrial and sewage wastes into the river through different tributaries. The concentration of zinc, lead and nickel in water was found dependent positively and significantly on water temperature. Iron and manganese showed negatively significant regression on dissolved oxygen. Increase in water hardness also significantly increased the iron, manganese and nickel concentration in water. There were significant variations in the concentration of heavy metals in effluent discharging tributaries. Same was true for the river stretch which might be due to changes in the volumes of industrial and domestic sewage waste, being added into the river. Water at Farrukhabad, Munshi hospital, Bakar Mandi nullas and Degh fall was highly polluted. Heavy metals loads in the six effluent discharging tributaries were significantly higher than the standard values set by the EPA (Pakistan) for municipal and liquid industrial effluent discharges. The water throughout the stretch of river was not suitable for aquatic life, freshwater fisheries and drinking purposes considering the criteria of the EPA, USA.

Key words: correlation, metal toxicity, physico-chemical variables, regression, River Ravi

INTRODUCTION

The study of river eco-toxicity has gained immense importance because of multiple use of river water for human consumption, agriculture and industry. The assessment of water quality lies on the delicate interface between physics, chemistry and biology, and study of these three aspects is useful in evaluation and abatement of pollution. River and natural waters have been widely utilized by mankind over the centuries, to the extent that very few, if any, are now in a natural condition. One of the most significant man-made changes has been the addition of chemicals to these waters. Since industrial, agricultural and domestic practice evolve changes and develop, therefore the types of chemical inputs, and thus their importance will be altered, leading to new problems that need to be investigated.

There are numerous sources of domestic and industrial effluents leading to heavy metal enrichment of water, sediments, vegetation and fish in rivers. A knowledge, of the distribution of heavy metals in water, sediments, plants and fish could play a key role in detecting sources of heavy metal pollution in aquatic systems (Forstner and Wittmann, 1981). Very few systematic studies have been undertaken in Pakistan (Javed and Hayat, 1995, 1996, 1998) to assess the magnitude of pollution in the River Ravi. The present investigation was undertaken to determine the metal toxicity of River Ravi water.

MATERIALS AND METHODS

The River Ravi from Shahdera to Baloki headworks was monitored at six sampling sites viz. Shahdera bridge (R1), Baradarri (R2), Sharqpur (R3), Thatta polian wala (R4), BS Q.B. link canal and Baloki headworks (R5), and Baloki headworks (R6). The main effluent discharging tributaries viz. Farrukhabad nulla (T1), Munshi hospital nulla (T2), Taj Company nulla (T3), Bakar Mandi nulla (T4), Hudiara nulla (T5) and Degh fall (T6) were monitored for their quality of water. Water samples from these sites were collected fortnightly from May 02, 1998 to April 30, 1999. The sample were collected between 09:00 a.m. and 12:00 noon. These were collected from just below the surface and column (two meters below the surface), mixed to have a composite sample for the heavy metals (zinc, iron, manganese, lead and nickel) and physico-chemical variables viz. water temperature, dissolved oxygen, pH, electrical conductivity and total hardness. Each sampling station was divided into six sub-stations, three each at right and left banks equidistant from the coming source (within the diameter of 100m). Water temperature, dissolved oxygen, pH and electrical conductivity were determined through HANNA HI-8053, HI-9143, HI-8520 and HI-8733 meters, respectively. Total hardness was determined according to S.M.E.W.W. (1989). Zinc, iron, magnesium, manganese, lead, and nickel concentrations in water were determined through atomic absorption spectrophotometer (Varian AA 10/20) by following the methods described in S.M.E.W.W. (1989).

Data were statistically analyzed using two-way classification (factorial experiment) by following Steel and Torrie (1986). Analysis of variance and Duncan's multiple range test were performed to evaluate differences among various parameters under study. Correlation and regression analyses were performed to relate various parameters under study.

RESULTS

Zinc: Mean zinc concentrations is water were maximum among the tributaries which ranged between 3.92 ± 2.04 mg 1-\ (at Farrukhabad nulla) and 0.50 ± 0.14 mg 1-\ (at Degh fall). However, the differences were non-significant between Munshi hospital nulla and Taj Company nulla. Among the river sampling sites, the mean zinc concentration in water at Sharqpur (R3) 'was the highest (0.88 ±- 0.45 mg I-I) while was the lowest at Shahdera bridge (Table 1). The effluent discharged from all the tributaries into the river significantly increased the zinc in river water at Baloki headworks.

Iron: The mean concentrations' of iron in tributary water were statistically the highest (11.89 ± 6.04 mg 1-1) at Farrukhabad nulla and was the lowest (3.24 ± 1.01 mg 1-\) at Hudiara. The difference between the mean iron concentration in the Taj Company nulla and that at Hudiara were non-significant.. In the river stretch, Thatta polian wala showed maximum mean iron concentration of 7.81 ± 1.78 mg 1-\ followed by 7.42 ± 3.57 mg 1-\at Baloki headworks which was significantly higher than that observed at Shahdera bridge (6.84 ± 2.70 mg 1'\).

Manganese: In tributary water, the mean concentration of manganese was maximum (3.07 ± 0.66 mg 1'1) at Farrukhabad nulla and was minimum (1.05 ± 0.17 mg 1'\) at Bakar Mandi nulla. In the river water at Baradarri, metal concentration was maximum (1.42 ± 0.44 mg 1'1) while it was the lowest at Thatta polian wala (0.89 ± 0.29 mg 1'1).The mean concentration of manganese at Baloki headworks was higher (0.78 ± 0.28 mg 1'\) than that at Shahdera (0.72 ± 0.37 mg I-I) but the difference was non-significant..

Lead: Lead in water fluctuated significantly among tributaries and river sampling stations. Among the tributaries, water of Farrukhabad nulla had the maximum mean lead concentration of 0.83 ± 0.29 mg 1'1 followed by that in the Bakar Mandi nulla. The lowest mean concentration of this metal was recorded at Degh fall site (0.54 ± 0.16 mg 1,1).In river water at Sharqpur, the highest mean concentration of 0.67 ± 0.25 mg 1'1 and lowest (0.25 ± 0.05 mg 1'1) at Shahdera site were recorded.

Nickel: Nickel concentration in water fluctuated significantly among the tributaries. Statistically, the highest mean concentration of nickel was recorded at Farrukhabad nulla (2.43 ± 0.27 mg 1-1)The minimum nickel contamination was recorded at Degh (0.69 ± 0,18 mg 1'\). At all the river site significant differences in nickel concentration except between Baradarri and Baloki headworks were observed. River water atSharqpur was found, highly polluted with nickel (0.75 ± 0.35 mg I-I). At Baloki, water contained significantly higher nickel than that at Shahdera.

Water Temperature: The mean temperatures of water in Farrukhabad, Taj Company and Bakar Mandi nullas were significantly the highest (Table 2). The river water temperature at all the sampling stations, except R5, varied non-significantly. The water temperature in all the tributaries was higher than that of the river water.

Electrical Conductivity: Among the tributaries, electrical conductivity of water was maximum (1983.04 ± 262.20 us) at Hudiara and was minimum (1038.30 ± 159.56 us) at Farrukhabad nulla (Table 2). In river, electrical conductivity values fluctuated significantly throughout the stretch under study, however, the difference between Shahdera and Baloki headworks was non-significant.. The mean electrical conductivity of tributary waters was 3.10 times higher than that of the river water.

Dissolved Oxygen: Water in Degh fall significantly contained the highest dissolved oxygen concentration (3,28 ± 0.58 mg 1'\) and was minimum at Farrukhabad nulla (0.97 ± 0.43 mg 1'1).In the river, dissolved oxygen at R5 was the maximum while it was the lowest at Thatta polian wala.

pH: The pH of tributary water fluctuated between 8.35 ± 0.37 (at Hudiara) and 7.31 ± 0.27 (at Taj Company nulla). The differences among T'l, T2 and T4 were statistically non-significant (Table 2). The mean water pH throughout the river stretch was above 8. At Baloki headworks, pH was significantly higher (8.32 ± 0.16) but was non-significantly .different from that at R4 and R5. River water had significantly higher pH than that of the tributary water.

Total Hardness: Total hardiness of water was significantly highest (491.80 ± 50.41 mg 1'1)at Hudiara nulla. At Thatta polian wala, river water had the highest mean hardness of 222.80 ± 46.22 mg 1-1 and was minimum at Shahdera bridge. River water at Shahdera was significantly softer than all the other sampling sites.

Metals Toxicity of River: Mean annual concentration of all the heavy metals, except zinc, in six effluent discharging tributaries were significantly higher than the standard values set by the Environment Protection Agency EPA (USA and Pakistan) fsr municipal and liquid industrial effluent discharges. The water throughout the stretch of river was not suitable for aquatic life, freshwater fisheries and drinking purposes (Table 3).

Relationships between metal toxicity of water and physico-chemical variable: The concentration of zinc, lead and nickel in water was positively dependent (P<O.OI) upon its temperature (Table 4). Dissolved oxygen showed negatively significant regression on iron, manganese and lead. Iron in water was also negatively (P<O.OI) dependent upon electrical conductivity. The regression coefficient for hardness was positively significant at P<O.OI. Manganese in water showed the same trend as that of iron in water. This relationship explains 91.58% variations for concentration of metal ions in water. Water temperature along with dissolved oxygen showed significant regression on lead concentration in water. Nickel was 46.48% dependent upon water temperature. The regression coefficient for this model was positively non-significant..

DISCUSSION

The bulk discharges of industrial wastes and domestic sewage into the river Ravi adversely affected the quality of water. However, maximum contribution was made by the Farrukhabad nulla towards metal pollution in the river. Brush *et al.* (1979) studied the heavy metals in the stretch of the Sasquenhanna river and found that the river was grossly polluted due to the discharge of urban and acid mine effluents into it. Javed and Hayat (1995) reported increased heavy metal contents in the River Ravi due to the discharges from municipal sewage, rubber, iron and paper mills effluents. Polprasert (1982) reported high concentrations of cadmium, copper, chromium, lead, zinc and mercury in the water and sediments of Chao Phraya river estuary in Thailand. The industrial and sewage input to the tributary rivers and direct discharges into the river Lagan were assumed the most likely sources of heavy metal contamination in tidal Lagan sediments (Manga, 1983).

The concentration of zinc in water was dependent positively and significantly on water temperature. Temperature change in a given direction may increase or decrease toxicity, depending on the toxicant and species (Macleod and Pessah, 1993). Zinc would be more lethal to a poikilothermic animals at high temperature (Hedson and Sprague, 1975). An important modifying factor in an aquatic habitat is temperature that affects ionization. Lloyd (1961) showed a 2.5 fold increase in metal toxicity for an increase in temperature from 7 to 20°C. Dissolved oxygen and pH appeared to be another variable that showed negative regression on the accumulation of metals in water. Stiff (1971) reported that lethal concentrations of toxic forms of copper were 200 - 2000 times higher at pH 5 than at pH 9, depending upon the hardness of water. Davies et al. (1976) found great differences in the toxicity of lead between soft and hard waters when the metal was measured as total concentration. However, during this investigation the increase in water hardness significantly increased the iron, manganese and nickel in water. It is expected that stresses on aquatic organisms caused by a reduction in ambient dissolved oxygen would greatly increase the toxicity of a pollutant in the water.

The heavy metal concentration in water depends mainly on the pH of the system (Javed and Hayat, 1999). The pH value of both tributaries and river water varied significantly. Metzner (1977) studied the fate of copper and zinc at different pH values in waste waters and found that the solubility of these metals were inversely proportional to the pH of the system and the highest solubility was found at pH 7 and below. Polprasert (1982) reported that the precipitation of heavy metals was enhanced at pB 7. Present observations agree with those of Metzner (1977) and Polprasert (1982) because significantly higher concentrations of heavy metals were detected in Farrukhabad, Munshi hospital, Taj Company and Bakar Mandi nullas, where the mean pH values of water varied between 7.31 ± 0.20 and 7.56 ± 0.37, were significantly lower than rest of the sampling sites. Javed and Hayat (1996) reported negative regression of pH on zinc, iron, manganese, cadmium, lead and nickel concentrations in polluted-waters. Electrical conductivity appeared to be another variable that influences the toxicity of zinc and manganese in water. Javed and Hayat (1995) also observed positive and significant dependence of zinc, iron and nickel concentrations in water on the electrical conductivity of water.

Conclusions:

1. During this study period the River water showed considerable variations for the concentration of heavy metals due to variable discharges of untreated industrial and sewage wastes into the river through different tributaries.
2. Water at Farrukhabad, Munshi Hospital, Bakar Mandi nullas and Degh fall was highly polluted with metals.
3. Heavy metals loads throughout the stretch of River Ravi, under investigation, was significantly higher than tlfe standard values set by the EPA (Pakistan, USA).

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Table 1. Mean concentrations of metals (mg l^{-1}) in water

	Effluent tributary sampling stations			River site sampling stations	
Zinc					
T1	Farrukhabad nulla	3.92 ± 2.04 a	R1	Shahdera bridge	0.52 ± 0.16 c
T2	Munshi hospital nulla	1.17 ± 0.06 d	R2	Baradarri	0.54 ± 0.15 c
T3	Taj Company nulla	1.12 ± 0.24 d	R3	Sharqpur	0.88 ± 0.45 a
T4	Bakar Mandi nulla	2.17 ± 0.93 b	R4	Thatta polian wala	0.69 ± 0.25 b
T5	Hudiara nulla	1.64 ± 0.60 c	R5	I/b Q.B. canal and Baloki headworks	0.57 ± 0.22 c
T6	Degh fall	0.50 ± 0.14 e	R6	Head Baloki	0.61 ± 0.24 b
	Means: Tributary water:	1.76 ± 1.19 a		River water:	0.63 ± 0.12 b
Iron					
T1	Farrukhabad nulla	11.89 ± 6.04 a	R1	Shahdera bridge	6.84 ± 3.70 d
T2	Munshi hospital nulla	5.72 ± 2.29 b	R2	Baradarri	7.16 ± 4.10 c
T3	Taj Company nulla	3.32 ± 1.07 e	R3	Sharqpur	6.02 ± 2.42 f
T4	Bakar Mandi nulla	4.27 ± 1.05 d	R4	Thatta polian wala	7.81 ± 1.78 a
T5	Hudiara nulla	3.24 ± 1.01 e	R5	I/b Q.B. canal and Baloki headworks	6.22 ± 2.17 e
T6	Degh fall	5.05 ± 1.78 c	R6	Head Baloki	7.42 ± 3.57 b
	Means: Tributary water:	5.58 ± 3.24 b		River water:	6.91 ± 0.69 a
Manganese					
T1	Farrukhabad nulla	3.07 ± 0.66 a	R1	Shahdera bridge	0.72 ± 0.37 d
T2	Munshi hospital nulla	1.46 ± 0.42 d	R2	Baradarri	1.42 ± 0.44 a
T3	Taj Company nulla	1.55 ± 0.44 bc	R3	Sharqpur	1.13 ± 0.48 b
T4	Bakar Mandi nulla	1.05 ± 0.17 e	R4	Thatta polian wala	0.89 ± 0.29 c
T5	Hudiara nulla	1.49 ± 0.41 cd	R5	I/b Q.B. canal and Baloki headworks	0.73 ± 0.35 d
T6	Degh fall	1.59 ± 0.91 b	R6	Head Baloki	0.78 ± 0.28 d
	Means: Tributary water:	1.70 ± 0.69 a		River water:	0.94 ± 0.28 b
Lead					
T1	Farrukhabad nulla	0.83 ± 0.29 a	R1	Shahdera bridge	0.25 ± 0.05 d
T2	Munshi hospital nulla	0.48 ± 0.09 f	R2	Baradarri	0.37 ± 0.08 b
T3	Taj Company nulla	0.69 ± 0.22 d	R3	Sharqpur	0.67 ± 0.25 a
T4	Bakar Mandi nulla	0.78 ± 0.30 b	R4	Thatta polian wala	0.36 ± 0.13 b
T5	Hudiara nulla	0.76 ± 0.16 c	R5	I/b Q.B. canal and Baloki headworks	0.29 ± 0.09 c
T6	Degh fall	0.54 ± 0.16 e	R6	Head Baloki	0.27 ± 0.08 c
	Means: Tributary water:	0.68 ± 0.14 a		River water:	0.37 ± 0.15 b
Nickel					
T1	Farrukhabad nulla	2.43 ± 0.27 a	R1	Shahdera bridge	0.46 ± 0.15 e
T2	Munshi hospital nulla	0.83 ± 0.14 e	R2	Baradarri	0.51 ± 0.20 d
T3	Taj Company nulla	0.90 ± 0.22 d	R3	Sharqpur	0.75 ± 0.35 a
T4	Bakar Mandi nulla	1.00 ± 0.19 b	R4	Thatta polian wala	0.58 ± 0.22 b
T5	Hudiara nulla	0.96 ± 0.23 c	R5	I/b Q.B. canal and Baloki headworks	0.55 ± 0.20 c
T6	Degh fall	0.69 ± 0.18 f	R6	Head Baloki	0.52 ± 0.19 d
	Means: Tributary water:	1.13 ± 0.64 a		River water:	0.56 ± 0.10 b

Means with similar letters in a column or row are statistically similar at $p < 0.05$.

Table 2. Mean values for physico-chemical parameters (±SD) of water

Effluent tributary sampling stations			River site sampling stations		
Temperature (DC)					
T1	Farrukhabad nulla	28.36 ± 5.52 a	RI	Shahdera bridge	26.16 ± 5.52 ab
12	Munshi hospital nulla	27.40 ± 5.00 c	R2	Baradarri	26.27 ± 5.27 ab
T3	Taj Company nulla	27.78 ± 5.15 abc	R3	Sharqpur	26.68 ± 4.84 a
T4	Bakar Mandi nulla	28.20 ± 5.61 a	R4	Thatta polian wala	26.35 ± 4.96 ab
T5	Hudiara nulla	27.60 ± 5.21 b	R5	lib Q.B. canal and Baloki headworks	25.16 ± 5.18 c
T6	Degh fall	25.48 ± 5.17 d	R6	Head Baloki	25.95 ± 5.25 b
	Means: Tributary water:	27.47 ± 1.04 a		River water:	26.09 ± 0.52 b
Electrical Conductivity (J,.I.s)					
T1	Farrukhabad nulla	1038.30 ± 159.56 d	RI	Shahdera bridge	299.40 ± 61.91 d
12	Munshi hospital nulla	1338.28 ± 87.87 b	R2	Baradarri	302.90 ± 54.54d
T3	Taj Company nulla	1167.94 ± 94.72 c	R3	Sharqpur	522.70 ± 88.64 b
T4	Bakar Mandi nulla	1174.99 ± 72.63 c	R4	Thatta polian wala	586.80 ± 188.64a
T5	Hudiara nulla	1983.04 ± 262.20 a	R5	lib Q.B. canal and Baloki headworks	340.60 ± 21.71 c
T6	Degh fall	604.09 ± 128.31 e	R6	Head Baloki	298.90 ± 60.17 d
	Means: Tributary water:	1217.77 ± 450.17 a		River water:	391.88 ± 128.73b
Dissolved Oxygen (mg I-I)					
T1	Farrukhabad nulla	0.97 ± 0.43 d	RI	Shahdera bridge	7.27 ± 0.45"
12	Munshi hospital nulla	2.10 ± 0.78 c	R2	Barndarri	6.82 ± 0.41 c
T3	Taj Company nulla	2.41 ±0.78 b	R3	Sharqpur	5.83 ± 0.58 d
T4	Bakar Mandi nulla	1.97 ± 0.90 c	R4	Thatta polian wala	5.64 ± 0.35 e
T5	Hudiara nulla	0.48 ± 0.42 e	R5	lib Q.B. canal and Baloki headworks	7.47 ± 0.57 a
T6	Degh fall	3.28 ± 0.58 a	R6	Head Baloki	6.88 ± 0.46 c
	Means: Tributary water:	1.87 ± 1.01 b		River water:	6.65 ± 0.75 a
pH					
T1	Farrukhabad nulla	7.45 ± 0.25 b	RI	Shahdera .bridge	8.12 ± 0.09 be
12	Munshi hospital nulla	7.53 ± 0.30 b	R2	Baradarri	8.00 ± 0.16 e
T3	Taj Company nulla	7.31 ± 0.27 c	R3	Sharqpur	8.0~ ± 0.22 be
T4	Bakar Mandi nulla	7.56 ± 0.37 b	R4	Thatta polian wala	8.30,± 0.19 a
T5	Hudiara nulla	8.35 ± 0.37 a	R5	lib Q.B. canal and Baloki headworks	8.22 ± 0.09 ab
T6	Degh fall	8.21 ± 0.14 a	R6	Head Baloki	8.32 ± 0.16 a
	Means: Tributary water:	7.73 ± 0.43 b		River water:	8.17 ± 0.13 a
Total Hardness (mg I-I)					
T1	Farrukhabad nulla	371.50 ± 37.11 c	RI	Shahdera bridge	178.40 ± 25.91 d
12	Munshi hospital nulla	378.50 ± 35.07 b	R2	Baradarri	193.40 ± 17.41 c
T3	Taj Company nulla	316.60 ± 44.81 d	R3	Sharqpur	215.90 ± 23.74 b
T4	Bakar Mandi nulla	309.10 ± 30.09 e	R4	Thatta polian wala	222.80 ± 46.22 a
T5	Hudiara nulla	491.80 ± 50.41 a	R5	lib Q.B. canal and Baloki headworks	188.10 ± 14.88 d
T6	Degh fall	216.60 ± 39.32 f	R6	Head Baloki	191.30± 45.57 cd
	Means: Tributary water:	347.35 ± 91.57 a		River water:	198.32 ± 17.22 b

Means with similar letters in a column or row are statistically similar at P<0.05.

Table 3. Water quality criteria for aquatic toxicity

Metals	EPA (USA) standard: Criteria for protection of fish EPA (USA)	EPA (USA) standard: Criteria for protection of aquatic life	EPA (Pak) standard: Criteria for drinking water(Max. cont. level)	EPA (Pak) standard: Municipal and liquid industrial effluents
Zinc	0.01 mg/l	0.01 mg/l	0.01 mg/l	5.00 mg/l
Iron	0.36 mg/l	NA	0.03 mg/l	2.00 mg/l
Manganese	0.50 mg/l	NA	0.05mg/l	1.50 mg/l
Lead	0.01 mg/l	0.01 mg/l	0.05 mg/l	0.50 mg/l
Nickel	0.01 mg/l	0.01 mg/l	0.001 mgll	1.00 mg/l

Table 4. Accumulation of heavy metals in water dependent upon physico-chemical parameters

			Regression euqation	rlMR	R2
Zinc		=	-17.77 + 0.71 (Temp.)	0.7748	0.6002
	SE	=	0.12**		
Iron		=	1.94 + 0.08 (Hard.) - 0.02 (E.C.) - 0.51 (DO)	0.9281	0.8614
	SE	=	0.008** 0.001** 0.18**		
Manganese		=	1.80 + 0.01 (Hard.) - 0.003 (E.C.) - 0.34 (DO)	0.9570	0.9158
	SE	=	0.001** 0.000** 0.038*		
Lead		=	-0.99 - 0.05 (DO) + 0.06 (Temp.)	0.8747	0.7651
	SE	=	0.01** 0.02*		
Nickel		=	- 8.06 + 0.33 (Temp.)	0.6817	0.4648
	SE	=	0.07N.S.		

* = Significant at $P<0.05$; ** = Significant at $P<0.01$; Temp. = temperature; N.S. = non-significant; E.C. = electrical conductivity; DO = dissolved oxygen; Hard. = total hardness

REFERENCES

Brush, E. J., M.M. Kalinowcki and L. Theodore. 1979. Heavy metals in a stretch of Sasquenhanna river badly polluted with acid mine effluents. Proc. Pak. Acad. Sci. 53: 179-188.

Davies, P.H., J.P. Goettle, J.R. Sinley and N.E. Smith. 1976. Acute and chronic toxicity of lead to rainbow trout *(Salmo giardneri)* in hard and soft water. Water Res. 10: 199-206.

Hedson, P.v. andJ.B. Sprague. 1975. Temperature-induced changes in acute toxicity of zinc to Atlantic Salmon *(Salmon salar).* J. Fish. Res. Bul. Can. 32: 1-10.

Forstner, U. and G.T.M. Wittmann. 1981. Metal Pollution in the AquaticEnvironment, Springer-Verlag,Berlin, Germany.

Javed, M. and S. Hayat. 1995. Effect of waste disposal on the water quality of river Ravi from Lahore to head Baloki, Pakistan. Proc. Pakistan Congr. Zool. 15: 41-51.

Javed, M. and S. Hayat. 1996. Planktonic productivity of river water as a bio-indicator of freshwater contamination by metals. Proc. Pakistan Congr. Zool. 16:383-398.

Javed, M. and S. Hayat. 1998. Fish as a bio-indicator of freshwater contamination by metals. Pak. J. Agri. Sci. 35:11-15.

Javed, M. and S. Hayat. 1999. Heavy metal toxicity of river Ravi aquatic ecosystem. Pak. J. Agri. Sci. 36:1-9.

Lloyd, R. 1961. Effect of dissolved oxygen concentrations on the toxicity of several poisons to rainbow trout *(Salmo giardneri).* J. Exp. Biol. 38: 447-455.

Macleod, J.C. and E. Pessah. 1993. Temperature effects on mercury accumulation, toxicity and metabolic rate in rainbow trout *(Salmo giardneri).* J. Fish. Res. Bul. Can. 30: 485-492.

Manga, N. 1983. Heavy metal concentrations in the sediments of the tidal section of the River Lagan. Ir. J. Environ. Sci. 2: 60-6~.

Metzner, A. V. 1977. Removing soluble metals from wastewater. Water Sewage Works. 124: 98-101.

Polprasert, C. 1982. Heavy metal pollution in the Chao Phraya river's estuary. Thailand. Water Res. 16: 775-784.

S.M.E.W.W. 1989. Standard Methods for the Examination of Water and Wastewater (17th Ed.) American Public Health Association, Washington, DC.

Steel, R.G.D. and J.H. Torrie. 1986. Principles and Procedures of Statistics: A Biometrical Approach (2nd Ed.). McGraw Hill Co. Inc., NY, USA.

Stiff, M. J. 1971. Copper-bicarbonate equilibria in solutions of bicarbonate ion at concentrations similar to those found in natural water. Water Res. 5: 171-176.