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HEAVY METAL TOXICITY OF RIVER RAVI AQUATIC ECOSYSTEM

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The assessment of river water quality has been made by physico-chemical and biological analyses. The role of plankton as indicators of freshwater contamination by heavy metals viz. zinc, iron, manganese, cadmium, lead and nickel has been studied through the computation of regression models. Significant variations in the concentration of heavy metals in water were due to changes in the volume of untreated industrial effluents and domestic sewage added continuously to the river system through. various effluent discharging tributaries. The concentrations of all heavy metals in water, except cadmium and mercury, were found significantly higher than the safe limits described by EPA (USA) for freshwater fisheries. The occurrence of all the heavy metals was negatively and significantly dependent upon the pH of water. The river water, throughout the stretch under study, was alkaline, however, decrease in pH of water significantly increased the heavy metal toxicity of water. Water temperature was another important factor which correlated positively and significantly ($P < 0.01$) with the occurrence of all heavy metals in river water. The uptake and accumulation of all the heavy metals (except lead) by the plankton were positively and significantly dependent on water temperature' also. The phytoplankton genera, viz. *Bumilleria, Cladophora, Chlorella, Fragilaria, Synedra, Scendesmus, Tabellaria* and *Zygnema* showed direct relationships with the intensity of metal pollution. Among zooplankton, *Brachionus* and *Polyarthra* were almost absent at highly polluted sampling stations. However, the genera viz. *Aphanizomenon, Bacillaria, Closterium, Cyclopedia, Cocconeis, Cosmarium, Chrococus, Denticulla, Euglena, Spirulina, Spirogyra* and *Volvox* showed considerable tolerance against heavy metal toxicity. *Keratella* and *Filinia* appeared to be the tolerant genera against heavy metal toxicity while *Cyclops* and *Philodena* were found as the sensitive forms. Metal ions in plankton have also shown direct relationships with the intensity of water pollution.

Key words: heavy metals, plankton, regression, toxicity

INTRODUCTION

The global production of organic chemicals has been raised tremendously during the last decade. The man-made toxic chemicals are released into the aquatic environment during production, transportation as well as utilization, and thus pose a threat to living biota. Therefore, the assessment of environmental hazards due to toxic substances is an important challenge to toxicologists. In Pakistan, particularly in the Punjab province, river Ravi pollution has greatly increased due to rapid industrialization and urbanization. Large quantities of untreated industrial effluents and domestic sewage are discharged daily into the riverine system without knowing its ill-effects on the aquatic habitats and consequently on human health. However, the awareness of its damaging effects, to the rivers and life they contain, to the seas to which the rivers flow, and on the people drinking this water, is gradually increasing. It is to be hoped that this awareness will lead to the abatement of the nuisance. In recent years, due to awareness about pollution, the programmes for the monitoring and abatement of water pollution including heavy metal toxicity in the rivers have been initiated (Ajmal et al., 1982; Lloyd, 1992; Braunbeck, 1994; Javed and Hayat, 1995, 1996, 1998).

The river Ravi is a monsoon type of river. The survey of the study area "from Shahdera to Baloki Headworks (about 65 km)" revealed that bulk discharges of untreated domestic and industrial effluents, through different tributaries, into the river Ravi at various points, adversely affected the physico-chemical and metal ion equilibrium of water. This points towards desperate need for assessing the problem and to develop methods for alleviating the ill-effects of pollutants, because polluted water can. cause paralysis, meningitis, cancer, sterility, schistosomiasis, poliomyelitis and filariasis in animals (Turk et al., 1972; Kumar, 1977; Singh et al., 1982).

MATERIALS AND METHODS

One year data (November, 1994 to October, 1995) on metal toxicity of water and plankton were collected from seventeen sampling stations selected throughout the stretch of river Ravi i.e. from Shahdera to head Baloki following proportionate sampling procedure (Steel and Torrie, 1986), at both right and left banks: 8hahdera Toll Tax bridge, right bank (8tation 1); in front of Baradarri (82); Farrukhabad nulla (83); 8harqpur (84); Thatta Polian wala (85); in between Q.B.link canal and Head Baloki (86); Head Baloki, right bank (87); 8hahdera Toll Tax bridge, left bank (88); Munshi Hospital nulla (89); Taj Company nulla (810); Bakar Mandi nulla (811); Choohang (812); 8undder (813); Head Baloki,left bank (814); Hudiara nulla (815); Q.B. link canal (816); Degh fall (817).

8amples were collected fortnightly during the morning hours between 9:00 a.m. to 12:00 noon. Water samples were collected from just below the surface and column (two meters below the surface), mixed to have a composite sample, for the heavy metals and physico-chemical variables. Each sampling. station was divided into three sub-stations, at equal distances from the coming source (within the diameter of lOOm). Water temperature, dissolved oxygen, pH, and electrical conductivity were determined through meter viz. HANNA HI-8053, HI-9143, HI-8520 and HI-8733 respectively. However, total hardness was determined through the method described in A.P.H.A. (1971). Zinc, iron, magnesium, manganese, cadmium, lead and nickel concentrations in water, were determined through atomic absorption spectrophotometer, by following method Nos. 3500-Zn· B, 3500-Fe B, 3500-Mg B, 3500-Mn B, 3500-Cd B,3500-Pb B, and 3500-Ni B respectively, while mercury concentrations were determined through dithizone method 3500-Hg C (8.M.E.W.W.,1989). The metal concentrations in plankton samples were also determined on dry weight basis. Dry samples of planktonic biomass were digested in perchloric and nitric acids and metal ion concentrations were determined by the atomic absorption spectrophotometer using the methods of 8.M.E.W.W. (1989) as mentioned above. Analysis of variance and Duncan's multiple range tests were performed to findout significant variations among different variables. Correlations and regression analyses were performed through computer packages (M8TATC & MICR08TAT) to findout relationships / trends among various parameters under study.

RESULTS

Data on physico-chemical. variables and mean annual concentrations of metals at 17 sampling stations are presented in Tables 1 and 2. Mean annual concentrations of all heavy metals (except cadmium and mercury) at all the sites were significantly higher than the standard values prescribed by the EPA (U8A) for safe freshwater fisheries (Table 3).

Relationships Among Physico-Chemical and Metal Ion Concentrations in Water: Step-wise regression of metallic ion concentrations in water on the physico-chemical variables were computed through step-wise regression method and final equations are presented in Table 4. The occurrence of all heavy metals in water was negatively (P< 0.01) dependent upon pH of water. Dissolved oxygen showed negatively significant regression on zinc, iron, nickel and mercury. However, iron and magnesium showed positively significant regression on water temperature. The availability of zinc in water was 71.30 % dependent upon the three variables viz. dissolved oxygen, pH and electrical conductivity. The partial regression coefficient for electrical conductivity was positively significant. The high values of R^2 for all the equations reveal high reliability of these regression models.

Heavy Metal Toxicity of Water and Plankton Dependent Upon Water Temperature and pH: The occurrence of all heavy metals in water was positively and significantly dependent upon water temperature. These relationships show direct dependence of metals in water changed positively with water temperature (Table 5). The regression of all the metals in plankton on water temperature was positively significant (except for lead). The uptake and accumulation of all the heavy metals in plankton were negatively and significantly dependent on pH of water. The regression of all metals in water was also inversely dependent on pH of water. The regression coefficients for all the variables were significant. The uptake and accumulation of heavy metals in plankton were also positively dependent upon the metallic ion concentrations in water. The regression coefficients for all the models, computed separately for each of the metals, were significant except for cadmium (Table 6).

Planktonic Productivity: Myxophyceae, Bascillariophyceae and Chlorophyceae were the important dominating groups distributed in the river throug-hout the period of study. Among phytoplankton, *Bumilleria, Cladophora, Chlorella, Fragilaria, Synedra, Scendesmus, Tabellaria* and *Zygnerna* indicated direct relationship with the intensity of pollution at highly polluted sites

Table 1. Mean annual concentration of (± SD) of heavy metals in water and planktonic biomass (dry weight at different sampling stations)

	Zinc		Iron		Manganese		Cadmium		Lead		Nickel	
	Water ($mg\ l^{-1}$)	Plankton ($\mu g\ g^{-1}$)	Water ($mg\ l^{-1}$)	Plankton ($\mu g\ g^{-1}$)	Water ($mg\ l^{-1}$)	Plankton ($\mu g\ g^{-1}$)	Water ($mg\ l^{-1}$)	Plankton ($\mu g\ g^{-1}$)	Water ($mg\ l^{-1}$)	Plankton ($\mu g\ g^{-1}$)	Water ($mg\ l^{-1}$)	Plankton ($\mu g\ g^{-1}$)
S1.	0.50 ± 0.22 [illegible]	62.73 ± 5.20 g	4.57 ± 1.75 efg	2190.11 ± 51.38 k	0.72 ± 0.52 [illegible]	308.11 ± 10.25 f	0.14 ± 0.07 [illegible]	7.25 ± .57 d	0.34 ± 0.19 fgh	4.25 ± 0.14 h	0.42 ± 0.17	8.28 ± 0.99 [illegible]
S2.	0.57 ± [illegible]	64.38 ± 3.25 fg	5.47 ± 2.64 c	4531.52 ± 40.17 e	[illegible]	[illegible] ± 15.35	[illegible]	8.18 ± 0.94	0.36 ± 0.19 efgh	6.00 ± 0.05 f	[illegible]	[illegible]
S3.	3.71 ± [illegible]	100.37 ± 3.35 a	10.80 ± 4.22	5387.55 ± 64.25 a	[illegible]	601.22 ± [illegible]	[illegible]	11.25 ± [illegible]	0.77 ± 0.20 a	9.44 ± 0.08 b	[illegible]	19.75 ± [illegible] a
S4.	0.67 ± [illegible]	[illegible]	[illegible]	5076.15 ± 50.50 b	[illegible]	384.35 ± 19.25	[illegible] cde	[illegible]	[illegible]	15.24 ± 0.13	[illegible]	8.37 ± [illegible]
S5.	0.64 ± [illegible]	[illegible]	[illegible]	4805.14 ± 35.91 d	[illegible]	381.53 ± 24.25	0.18 ± 0.07 defg	[illegible]	[illegible]	5.30 ± [illegible]	[illegible]	[illegible]
S6.	[illegible]	[illegible]	[illegible]	2016.16 ± 28.95 l	[illegible]	[illegible] ± 16.91	0.12 ± 0.06	[illegible]	[illegible]	3.95 ± [illegible]	[illegible]	[illegible]
S7.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] ± 12.38	[illegible]	[illegible]	[illegible]	2.97 ± [illegible] i	[illegible] de	[illegible]
S8.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.42 ± 0.16 de	[illegible]
S9.	[illegible] c	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] ± 18.35	[illegible]	[illegible]	[illegible]	[illegible] ef	0.76 ± 0.13 b	[illegible]
S10.	1.83 ± 0.39 c	[illegible]	[illegible]	[illegible] f	[illegible]	[illegible] ± 14.55	[illegible]	[illegible]	[illegible]	8.35 ± 0.09	[illegible]	[illegible] efg
S11.	2.21 ± [illegible]	[illegible] ± 7.00	[illegible] cde	3974.28 ± 34.19 i	[illegible]	[illegible]	[illegible]	[illegible] f	[illegible]	[illegible]	[illegible]	8.11 ± 0.29 fg
S12.	[illegible]	[illegible]	5.37 ± 1.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.52 ± [illegible]	7.25 ± 0.35 ij
S13.	0.61 ± [illegible]	[illegible]	[illegible]	[illegible] j	[illegible]	[illegible] ± 13.50	[illegible]	[illegible]	[illegible]	[illegible]	0.47 ± [illegible]	7.42 ± 0.54 ij
S14.	[illegible]	[illegible]	[illegible]	1312.14 ± 30.58 p	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.02 ± [illegible]	[illegible] de	8.67 ± 0.39 e
S15.	1.57 ± [illegible]	[illegible]	[illegible]	1147.58 ± 51.75	[illegible]	[illegible] ± 12.25	[illegible]	[illegible]	[illegible]	[illegible]	0.75 ± 0.12 b	10.10 ± 0.31 c
S16.	0.40 ± 0.18 f	[illegible]	[illegible]	[illegible] o	[illegible]	[illegible] ± 14.22	[illegible] g	6.22 ± 0.42	[illegible]	[illegible]	0.25 ± 0.07 f	6.39 ± 0.51 k
S17.	0.58 ± 0.22 ef	[illegible] k	[illegible] cdef	[illegible]	[illegible]	[illegible] ± 12.56 f	0.23 ± 0.07 cd	5.98 ± 0.65	[illegible]	[illegible]	0.61 ± [illegible]	9.37 ± 0.59 d

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

Table 2. Mean values (± SD) for metal concentrations and physico-chemical characteristics of river water

S.S	Temperature (°C)	Dissolved oxygen (mg l^{-1})	pH	Electrical conductivity (µS)	Total hardness (mg l^{-1})
S1	24.97 ± 0.21 f	7.63 ± 0.16 b	8.29 ± 0.04 bcd	336.31 ± 8.67 ij	169.54 ± 11.85 ij
S2	25.76 ± 0.09 e	7.00 ± 0.14 d	8.23 ± 0.01 d	392.43 ± 1.82 g	1~2.22 ± 6.67 fg
S3	30.75 ± 0.56 a	1.82 ± 0.28 i	7.51 ± 0.05 g	998.18 ± 43.64 c	307.29 ± 16.87 c
S4	25.97 ± 0.09 e	6.40 ± 0.07 e	8.26 ± 0.01 cd	514.60 ± 10.29 e	215.40 ± 17.70 de
S5	24.86 ± 0.16 f	5.58 ± 0.19 fg	8.38 ± 0.03 ab	485.15 ± 18.77 e	207.49 ± 11.50 e
S6	23.74 ± 0.29 gh	7.44 ± 0.16 bc	8.32 ± 0.05 bcd	379.50 ± 9.55 gh	172.16 ± 14.31 i
S7	23.38 ± 0.38 hi	7.38 ± 0.27 bc	8.32 ± 0.03 bcd	319.61 ± 3.46 ij	167.78 ± 3.99 ij
S8	24.81 ± 0.01 f	7.23 ± 0.23 cd	8.35 ± 0.03 bc	347.17 ± 1.40 hi	175.80 ± 1.98 hi
S9	27.89 ± 0.52 c	1.94 ± 0.18 i	7.59 ± 0.05 fg	1090.93 ± 2.08 b	320.06 ± 11.31 b
S10	28.60 ± 0.50 b	2.52 ± 0.22 h	7.70 ± 0.03 e	1092.09 ± 24.90 b	321.42 ± 10.10 b
S11	29.07 ± 0.20 b	1.89 ± 0.18 i	7.66 ± 0.11 ef	1118.56 ± 9.02 b	310.66 ± 25.09 bc
S12	24.73 ± 0.06 f	5.82 ± 0.20 f	8.31 ± 0.01 bcd	558.39 ± 8.24 d	204.75 ± 12.29 ef
S13	23.71 ± 0.35 gh	6.46 ± 0.31 e	8.26 ± 0.02 cd	446.91 ± 11.64 f	186.85 ± 0.27 gh
S14	22.98 ± 0.66 i	7.29 ± 0.29 bc	8.30 ± 0.02 bcd	312.61 ± 14.40 j	165.60 ± 1.39 ij
S15	27.06 ± 0.17 d	1.67 ± 0.33 i	8.24 ± 0.03 d	1601.73 ± 18.51 a	400.71 ± 22.47 a
S16	23.23 ± 0.02 hi	8.26 ± 0.04 a	8.47 ± 0.04 a	279.27 ± 5.78 k	158.45 ± 0.58 j
S17	24.39 ± 0.36 fg	5.39 ± 0.31 g	8.36 ± 0.002 b	570.73 ± 7.00 d	224.93 ± 12.12 d

Means with similar letters in a single column are statistically similar at $P < 0.05$.

Table 3. Water quality criteria for freshwater fish, aquatic life, drinking purpose and environmental quality control standards (EQCS) for municipal and liquid industrial effluents described by EPA (USA and Pakistan)

Metals	Criteria for protection of fish EPA (USA)	Criteria for protection of aquatic life EPA (USA)	Criteria for drinking water (Max. cont. level) PHSDWS**	EQCS for municipal and liquid industrial effluents (EPA Pak.)
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	0.05 mg/l	1.50 mg/l
Cadmium	1.20 mg/l	12.00 mg/l	0.01 mg/l	0.10 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 mg/l	1.00 mg/l
Mercury	0.03 mg/l	0.05 mg/l	0.002 mg/l	0.01 mg/l

Table 4. Regression of heavy metals on the selected physico-chemical variables

Regression equation	rIMR	R^2
Zinc = 7.078 - 0.104** (D.O.) - 0.717 (pH) + 0.0004 (E.C.) (0.018) (0.062) (0.0001)	** 0.844	** 0.713
Iron = 15.115 + 0.230** (W.T.) - 0.004** (KC.) - 1.489** (pH) - 0.341** (D.O.) (0.015) (0.0004) (0.269) (0.077)	0.884	0.781
Magnesium = 18.345 + 0.015** (KC.) - 2.000** (pH) + 0.076* (W.T.) (0.0003) (0.288) (0.017)	0.965	0.931
Manganese = 7.424 - 0.844** (pH) + 0.002** (T.H.) (0.057) (0.0002)	0.816	0.666
Cadmium = 1.148 - 0.114** (pH) (0.046)	0.779	0.607
Lead = 1.479 + 0.002** (T.H.) - 0.153** (pH) - 0.006** (W.T.) - 0.0001** (KC.) (0.0001) (0.017) (0.001) (0.00003)	0.888	0.789
Nickel = 3.611 - 0.026** (D.O.) - 0.371** (pH) - 0.001** (T.H.) (0.007) (0.030) (0.0002)	0.828	0.685
Mercury = 0.034 - 0.001** (D.O.) - 0.003** (pH) - 0.0001** (W.T.) + 0.Ob001** (T.H.) (0.00005) (0.0002) (0.00001) (0.000001)	0.880	0.774

** = Significant at P<O.01; D.O. = Dissolved oxygen; W.T. = Water temperature; T.H. = Total hardness; E.C. = Electrical conductivity.

because these genera were almost absent or had significantly low densities at Farrukhabad .nulla (83), Munshi Hospital nulla (89), Taj Company nulla (810), Bakar Mandi nulla (811), Hudiara nulla (815) and Degh fall (817). Among zooplankton populations, *Brachionus* and *Polyarthra* were almost absent at highly polluted sampling sites. However, the genera *Aphanizomenon, Bacillaria, Closterium, Cyclotella, Cocconeis, Cosmarium, Chrococus, Denticulla, Euglena, Spirulina, Spirogyra* and *Volvox* showed considerable tolerance against heavy metal toxicity at different sampling stations. *Keratella* and *Filinia* appeared to be the tolerant genera against heavy metal toxicity while *Cyclops* and *Philodena* were found as the sensitive forms.

DISCUSSION

The present data show significant variations in metallic ion concentrations of water among different effluent discharge tributaries and river site sampling stations situated along both left and right banks of the river (Tables 1 and 2). High concentrations of all the heavy metals (except manganese) were recorded at Farrukhabad nulla (83). The other highly polluted sites were Bakar Mandi nulla (811), Munshi Hospital nulla (89), Hudiara nulla (815), Taj Company nulla (810) and Degh fall (817). There was considerable deterioration in the quality of the river water at discharge points of Farrukhabad nulla (83), Bakar Mandi nulla (811), Munshi Hospital nulla (8H), Hudiara nulla (815), Taj Company nulla (810) and Degh fall (817). The quality of river water improved gradually after Bakar Mandi nulla (811) onwards, except at Hudiara nulla where this river received large quantities of wastewater deteriorating its quality significantly. There was gradual improvement in the quality of river water at Baloki Headworks due to merging of less polluted tributary Le. Q.B. link canal, into the river. Significantly higher concentrations of heavy metals in water of

Table 5. Dependence of heavy metal toxicity of water and plankton on water temperature and pH

Regression equation (Y = a + bx)		r	Regression equation (Y = a + bx)		r
Zinc			Cadmium		
In water =	23.22 + 2.46 (W.Temp.) (0.224)	0.943**	In water =	20.14 + 26.64 (W.Temp.) (2.692)	0.931**
In water =	8.49 - 0.34 (pH) (0.042)	- 0.902**	In water =	8.92 - 3.68 (pH) (0.464)	- 0.898**
In plankton =	16.42 + 0.14 (W.Temp.) (0.030)	0.768**	In plankton =	23.53 + 0.34 (W.Temp.) (0.310)	0.572*
In plankton =	9.34 - 0.02 (pH) (0.005)	- 0.687**	In plankton =	8.39 - 0.04 (pH) (0.045)	- 0.410*
Iron			Lead		
en water =	21.59 + 0.81 (W.Temp.) (0.255)	0.832**	In water =	19.68 +14.29 (W.Temp.) (1.615)	0.916**
In water =	8.71- 0.11 (pH) (0.038)	- 0.596**	In water =	8.94 - 1.86 (pH) (0.317)	- 0.834**
In plankton =	22.86 + 0.001 (W.Temp.) (0.0001)	0.599**	In plankton =	23.02 - 0.42 (W.Temp.) (0.181)	0.514*
In plankton =	8.54 - 0.0001 (pH) (0.00001)	-0.568**	In plankton =	8.45 - 0.05 (pH) (0.028)	- 0.428*
Manganese			Nickel		
In water =	22.62 + 3.06 (W.Temp.) (0.501)	0.844**	In water =	22.53 + 5.17 (W.Temp.) (0.824)	0.851**
In water =	8.56 - 0.40 (pH) (0.084)	- 0.776**	In water =	8.56 - 0.66 (pH) (0.145)	- 0.764**
In plankton =	17.81 + 0.02 (W.Temp.) (0.004)	0.814**	In plankton =	21.36 + 0.49 (W.Temp.) (0.154)	0.637**
In plankton =	9.19 - 0.003 (pH) (0.001)	- 0.746**	In plankton =	8.65 - 0.06 (pH) (0.025)	- 0.511*

Values within brackets are standard errors.
NS = Non significant; ** = Highly significant (P<O.Ol); W.Temp. = Water temperature.

Table 6. Regression of metal ion concentrations in plankton on metal ion concentration in water

Regression equation (Y = a + bx)					r
Zn in plankton =	55.18	+	11.67 (2.18)	(Zn in water)	** 0.810
Fe in plankton =	- 177.75	+	656.99 (137.44)	(Fe in water)	** 0.777
Mn in plankton =	228.33	+	113.37 (15.20)	(Mn in water)	** 0.887
Cd in plankton =	6.21	+	2.08 (5.89)	(Cd in water)	NS 0.091
Pb in plankton =	2.36	+	9.83 (4.22)	(Pb in water)	* 0.516
Ni in plankton =	4.54	+	7.07 (0.89)	(Ni in water)	** 0.899

Values within brackets are standard errors. NS = Non significant; ** = Highly significant (P<O.OI).

effluent discharge tributaries were the result of industrial and municipal wastewater which significantly increased the heavy metal toxicity of river water. Polprasert (1982) reported high concentrations of cadmium, copper, chromium, lead, zinc and mercury in the water and sediments of Chao Phraya river's estuary in Thailand due to the bulk discharges of domestic and industrial effluents into the river. Manga (1983) reported that the industrial effluent input to the tributary rivers and direct discharges into the river Lagan were the most likely sources of heavy metal contamination in tidal Lagan sediments.

The occurrence of heavy metals in aquatic habitats is dependent upon a wide range of chemical, biological and environmental factors. Among the physico-chemical factors, an important factor which influences the availability of different heavy metals in the aquatic ecosystem is the hydrogen ion concentration (Polprasert, 1982). The occurrence of all the heavy metals was negatively and significantly dependent upon the pH of water (Table 5). However, the water of river, throughout the stretch under study, remained alkaline, but decrease in pH of water resulted in significant increase in heavy metal toxicity of water. Metzner (1977) reported increase in lead and zinc solubility in water with the decrease in pH and the highest solubility of these metals were recorded at pH 7. Boqomazov et at (1991) observed an inverse relationship between water pH and concentration of mobile iron, mercury, zinc and cobalt. Water temperature appeared to be another important factor which correlated positively and significantly ($P < 0.01$) with the occurrence of all heavy metals in river water (Table 5). The values of correlation coefficients (r) for all the metals ranged between 0.832 and 0.943, which showed almost linear regression of these metals on water temperature. The uptake and accumulation 'of all the heavy metals (except lead) by the plankton were also positively and significantly dependent on water temperature (Table 5). Jackson (1988) reported increase in metal uptake by benthos with the decrease in water temperature. However, bio-dilution had no significant effect on mercury accumulation by benthos or plankton.

Table 4 shows negatively significant regression of zinc, iron, nickel and mercury on dissolved oxygen contents of river water because of the proliferation of oxygen consuming decomposers, with the increase of metal ions in water, mainly bacteria and fungi are encouraged (Ajmal and Razi-ud-Din, 1988). These decomposers reduce the oxygen supply and consequently, members of aquatic communities especially fish and shell fish, become deprived of aquatic oxygen and perish. Since the accumulation of all the metals in plankton showed positively significant (except for cadmium) dependence on the metal ion concentrations in water (Table 6), thus the potential of plankton to concentrate heavy metals, from aquatic environments into their bodies is evident (Bryan and Hummerstone, 1973; Harding and Whitton, 1981). Ajmal and Razi-ud-Din (1988) reported significantly positive correlation between the heavy metals viz. cobalt, chromium, copper, iron, manganese, nickel, lead and zinc in water and submerged vegetation of Hindon river, India. The present data indicated that the plankton has a great tendency to accumulate metals in their bodies from water and sediments (Lee and Keeney, 1975; Khan et al., 1981). The uptake and accumulation of heavy metals by the plankton from the water and sediments are obvious and that may be the reason of elevated levels of metals in plankton collected from highly polluted river sites.

The maximum levels of metals in water at effluent discharging tributaries viz. Farrukhabad nulla (S3), Munshi Hospital nulla (S9), Taj Company nulla (S10), Bakar Mandi nulla (S11), Hudiara nulla (S15) and Degh fall (S17) had resulted in significant uptake of metals by the plankton that resulted in the perishment of phytoplankton genera like *Bumilleria, Cladophora, Chlorella, Fragilaria, Synedra, Scendesmus, Tabellaria* and *Zygnema.* These genera showed direct relationship with the intensity of pollution. Among zooplankton, *Brachionus* and *Polyarthra* were almost absent at highly polluted sampling sites (Table 7). However, *Aphanizomenon, Bacillaria, Closterium, Cyclotella, Cocconeis, Cosmarium, Chrocous, Denticulla, Euglena, Spirulina, Spirogyra* and *Volvox* showed considerable tolerance against heavy metal toxicity. *Keratella* and *Filinia* appeared to be the tolerant genera against heavy metal toxicity while *Cyclops* and *Philodina* were found as the sensitive forms. Palharya and Malvia (1988) reported *Spirulina, Nostoc, Oscillatoria* and *Anabaena* as dominant and resistant forms against heavy metal toxicity in Narmada river, India. However, Unni (1986) reported *Keratella, Tropica, Filinia* and *Polyarthra* as tolerant forms against heavy metals toxicity. The bio-indicator organisms have been used by many authors to monitor the time averaged abundance of metals and other pollutants in the aquatic environments. Harding and Whitton (1981) suggested that the chemical analyses of the tissues of submerged plants may give valuable information about the contamination of the surrounding water. An analysis of bladder wrack *(Fucus vesiculosus)* populations in coastal Irish sea and North sea for zinc, iron, manganese, copper, nickel, lead, silver and cadmium showed the accumulation of these metals in this species of brown algae (Preston et al., 1972). Keeney et al. (1976) reported that metal contamination in the *Cladophora glomerata* algae was dependent on the heavy metal concentration in their environment.

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REFERENCES

Ajmal, M., AA Nomani and M.A Khan. 1982. Quality of Ganga river in Utter Pradesh and Bihar, LAW.P.C. Tech. Annual, 9: 165-166.

Ajmal, M. and Razi-ud-Din. 1988. Studies on the pollution of Hindon river and Kali Nadi (India). Ecology and Pollution of Indian rivers. Ashish Publishing House, New Delhi: 447.

AP.H.A.. 1971. Official Methods for the Examination of Water and Wastewater, Washington, D.C.

Boqomazov, N.P., LA. Shilnikov, S.M. Soldatov, S. N. Lebedev and Shilnikov. 1991. Effect of the **pH** of leached chernozem on mobility of iron and micronutrients (a model experiment). Sov. Soil Sci. 23(8): 44-46.

Braunbeck, T. 1994. Detection of environmentally relevant concentrations of toxic organic compounds using histological and cytological parameters: Substance-specificity in the reaction of rainbow trout liver. **In** Sub-lethal and Chronic Effects on Freshwater Fish. - Fishing News Books.Oxford,

Bryan, G.W. and L.G. Hummerstone. 1973. Brown seaweed as an indicator of heavy metals in estuaries in south-west England. J. Mar. Biol. Assoc. 53: 705 - 720.

Harding, J.P.C. and B.A Whitton. 1981. Accumulation of zinc, cadmium and lead by field populations of Lamanea. Water Res. 15:301-319.

Jackson, T.A 1988. Accumulation of mercury by plankton and benthic invertebrates in riverine lakes of northern Manitoba (Canada): Importance of regionally and seasonally varying environmental factors. Can. J. Fish. Aqua. Sci. 45(1): 1744 - 1757.

Javed, M. and S. Hayat. 1995. Effect of waste disposal on the water quality of river Ravi from

Lahore to head Baloki, Pakistan. Proc. Pak. 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. Pak. Congr. Zool. 16: 283 - 298.

Javed, M. and S. Hayat. 1998. Fish as a bio-indicator of freshwater contamination by metals. Pak. J. Agri. Sci. 35 (1-4): 11 - 15.

Keeney, W.L., W.G. Breck, G.W. VanLoon and J.A. Page. 1976. The determination of trace metals in *Cladophora glomerata* as a potential biological monitor. Water Res. 10: 981 - 984.

Khan, N.A, A Ahmad, AA Nomani and M. Ajmal. 1981. Atomic absorption spectrophotometric studies on commercial fertilizers as a source of Cd and Zn in soil and river water. Environ. Pollu. 13(2): 259- 264.

Kumar, H.D. 1977. Modern Concept of Ecology, 1st ed. Vikas Publishing House Pvt. Ltd. New Delhi: 107 - 138.

Lee, KW. and D. R Keeney. 1975. Spectrophotometric determination of cadmium and zinc in soil and commercial fertilizers. Water Air Soil Pollu. 5:109-112.

Lloyd, R 1992. Pollution and Freshwater Fish. Fishing News Books, Oxford.

Manga, N. 1983. Heavy metal concentrations in the sediments of the tidal section of the river Lagan. Ir. J. Environ. Sci. 2 : 60-64.

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

Palharya, J.P. and S. Malvia. 1988. Pollution of the Narmada river at Hoshangabad in Madhya Pradesh and suggested measures for control. Ecology and Pollution of Indian Rivers. Ashish Publishing House, New Delhi: 447.

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

Preston, A, D.F. Jefferies, J. Dutton, B. Harveyand AK Steele. 1972. The concentration of selected heavy metals in sea water. Environ. Pollut. 3: 69 - 82.

Singh, R, S. Parthak and V.P. Singh. 1982. Hazards of water pollution in human life. Ab. 1st N.E.C. 15 - 16.

S.M.E.W.W. 1989. Standard Methods for the Examination of Water and Wastewater 07th ed.), AP.H.A, Washington, DC.

Steel, RG.D. and J.H. Torrie. 1986. Principles and Procedures of Statistics: A Biometrical Approach (2nd ed.). McGraw Hill Co. Inc., New York: 633.

Turk, A, J. Turk and J.T. Wltes. 1972. Ecology, Pollution, Environment. W.B. Sunders Comp. Philadelphia: 109 - 134.

Unni, KS. 1986. Biological indicators of water pollution, Abst. Int. Workshop on Surf. Water Mang., Bhopal, l\LP.