Studies on Metals Eco-toxicity of the River Ravi

FINAL RESEARCH REPORT

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SUMMARY

By integrating the chemical, toxicological and ecological data, the impact of heavy metals pollution on the river Ravi stretch from Shahdera bridge to Sidhnai barrage was assessed. The role of both plankton and fish as indicators of freshwater contamination by metals has been studied. The present investigation reveals that metals eco-toxicity of river Ravi has crossed the safe limits for sustainable conservation of aquatic habitats as described by the Environmental Protection Agency (EPA), USA.

The heavy metals toxicity of water, plankton and sediments at Farrukhabad, Bakar Mandi, Munshi Hospital, Hudiara, Taj Company nullas, Degh nulla I and II, Sammundri and Sukhrawa main drains were extremely high and there has been an increasing tendency towards accumulation of metals in water, fish, plankton and sediments in riverine ecosystem. Considerable deterioration in the quality of river water was recorded at discharge points of Farrukhabad, Bakar Mandi, Munshi Hospital, Hudiara, Taj Company and Degh nullas. The quality of river water improved gradually onwards, after Bakar Mandi nulla, except at Khurd Pur (the point where Hudiara nulla enters river Ravi) where this river receives large quantities of wastes deteriorating its water quality. The gradual improvement in the quality of river water at Baloki headworks was due to merging of less polluted tributary i.e., Q. B. Link Canal, into the river. The river stretch from Baloki headworks to Sidhnai barrage receives bulk discharges of contaminated water from Degh nulla II, Sammundri and Sukhrawa main drains and ultimately deteriorating the quality of water at Sidhnai barrage.

All the three freshwater fish species, viz. *Catla catla, Labeo rohita* and *Cirrhina mrigala* (major carps) are on the verge of extinction in the river Ravi due to heavy loads of metals in water, plankton, sediments. Three fish species showed significant variations for the accumulation of metals in their bodies. *Catla catla* showed significantly higher tendency to accumulate metals in its body than *Labeo rohita* and *Cirrhina mrigala*. The fish at Sidhnai barrage showed significantly higher metal contamination than that at Baloki headworks. Fish liver appeared to be an organ which had significantly higher tendency for the accumulation of iron, zinc and lead while nickel and manganese accumulations were the maximum in fish skin and gills respectively.

All the metal ions, except lead, in sediments and plankton have shown direct relationships with the intensity of water pollution. **Thus, both these components of aquatic ecosystem could act as indicators of metal pollution in freshwaters.** Regarding the stretch of river from Shahdera to Baloki headworks, the phytoplankton, viz. *Aphanocapsa, Bacillaria, Closterium, Cyclotella, Cocconeis, Cosmarium, Denticulla, Dinobryon, Euglena, Pinnularia, Spirulina* and *Spirogyra* showed considerable tolerance against heavy metals toxicity both in tributaries and river. Among the zooplankton, *Keratella, Cyclops, Monnstyla* and *Filinia* were the sensitive forms and showed their existence according to the severity of pollution at different sites. The river stretch, from Baloki headworks to Sidhnai barrage showed Myxophyceae, Bacillariopgyceae and Chlorophyceae as the important groups distributed with variable densities. Among phytoplankton, *Aphanocapsa, Bumilleria, Bacillaria, Cladophora, Cocconeis, Eudorina, Microcystis, Pandorina, Scendesmus, Volvox* and *Zygnema* indicated direct relationships with the intensity of pollution. Among zooplankton, the genus, viz. *Bosmina, Filinia, Keratella* and *Monnstyla* showed considerable tolerance against metallic ion pollution. *Daphnia* appeared to be a sensitive form against metal pollution in water.

The bulk discharges of industrial effluents and domestic sewage into the river Ravi have badly affected the quality of water. However, if we consider rivers as the renal systems of the land spaces then, this kidney system is close to the renal failure at river Ravi. Hence, it is imperative that appropriate steps should be taken by both the Governmental and public agencies to restore river Ravi from effluent tributary to a natural riverine condition.

PROJECT TITLE: Studies on metals eco-toxicity of the river Ravi.

PROJECT PERIOD: Three Years (From May 02, 1998 to April 30, 2001)

INTRODUCTION

Rivers and lakes are a very important part of our natural heritage. They 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, containing a lot of heavy metals, to the waters. Such inputs to water can be derived from a variety of sources, some of them obvious, and others less so. They can be varied so that the concentrations of chemicals in water are rarely constant. Contaminated sediments are another significant source of water pollution. These may be derived from inputs of suspended solids to which toxic substances are absorbed, such as soil particles in surface water run-off from fields treated with pesticides. Alternatively, the natural suspended material in a watercourse as well as the river bed surface can adsorb chemicals and metals from water. When the suspended material settles down, the toxic material forms a sink or reservoir; the extent to which this can cause harm to aquatic life depends on the strength of the bond between chemical and particles. Thus, a knowledge of the distribution of heavy metals in water, sediments and plankton play a key role in detecting sources of heavy metal pollution in aquatic ecosystem (Forstner and Wittmann, 1981; Javed and Hayat, 1999). Braunbeck (1994) detected environmentally related concentrations of organic compounds using histological and cytological parameters in rainbow trout liver. From an ecological point of view, survival, growth, reproduction, spawning and hatching success, in fish under different levels of toxicity, provide end-points of undoubted significance. Since reaction and adaptation to environmental parameters, regardless of whether they are natural or man-made, are hierarchical process involving different levels of biological organization (Lloyd, 1992; Vogt, 1987), macroscopically overt signs of toxicity are almost always preceded by changes at the organ, tissue, cellular, and molecular levels (Segner and Braunbeck, 1990).

Toxic heavy metal pollutants are increasingly being released to the environment as a result of industrialization. Metals are the problem of magnitude and of ecological significance due to their high toxicity and ability to accumulate in living organisms (Jensen and Bro–Rasmussen, 1992). Amongst fish species, considerable differences in sensitivity to different metals have been reported. Salmonids are greatly sensitive to high cadmium level (Suresh *et al,* 1993). Heavy metal inputs from natural resources, mining practices, industrial effluents and domestic sewage are likely to enter inland aquatic ecosystems that would accumulate in the fish and result in the physiological perturbations. Studies have been conducted to assess the metals ecotoxicity in river ecosystems in Pakistan by Javed, 1999; Javed and Hayat; 1995, 1996. During this investigation, the magnitude of metal pollution in water, sediments, plankton and fish in the river stretch from Shahdera to Sidhnai barrage has been studied.

EXPERIMENTAL PROCEDURE

FIRST YEAR OF THE PROJECT:

STUDY AREA	:	From Shahdera to Baloki headworks (Figure 1)
DURATION OF WORK	:	12 Months (from May 02, 1998 to April 30, 1999)

The stretch of river Ravi, i.e. from Shahdera to Baloki headworks was monitored at six sampling sites (Figure 1). Each of which was divided into six sub-stations, three at each right and left banks of the river as follows:

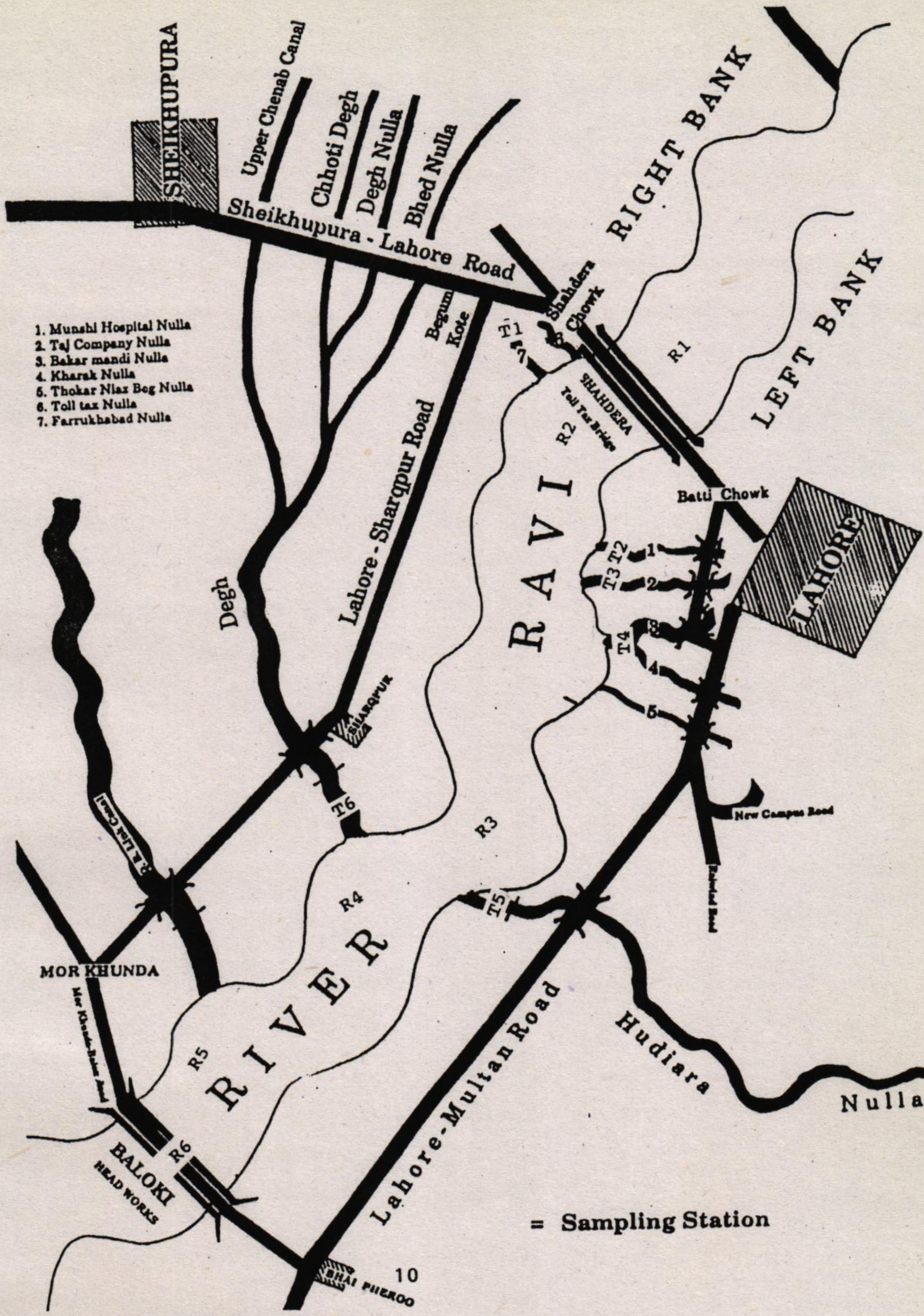
River Site Sampling Stations:

Shahdera bridge	(R1)
Baradarri	(R2)
Sharqpur	(R3)
Thatta polian wala	(R4)
I/B Q.B. link canal and Baloki headworks	(R5)
Baloki headworks	(R6)

Effluent Discharging Tributaries:

Farrukhabad Nulla	(T1)
Munshi Hospital Nulla	(T2)
Taj Company Nulla	(T3)
Bakar Mandi Nulla	(T4)
Hudiara Nulla	(T5)
Degh Fall	(T6)

Figure: 1 Map of the study area from Shahdera to Baloki headworks.



River Sampling Stations:

R1	Shahdera bridge
R2	Baradarri
R3	Sharqpur
R4	Thatta polian wala
R5	I/B Q.B. link canal and Baloki headworks
R6	Baloki headworks

Effluent Discharging Tributaries:

T1	Farrukhabad Nulla
T2	Munshi Hospital Nulla
T3	Taj Company Nulla
T4	Bakar Mandi Nulla
T5	Hudiara Nulla
T6	Deg Fall

SURVEY REPORT:

PROJECT AREA: From Baloki headworks to Sidhnai barrage

During the first six months of the project, the stretch of river Ravi, i.e. from Baloki headworks to Sidhnai barrage was also surveyed for the identification of different effluent discharging tributaries along both right and left banks (Figure 2).

River Ravi originates from India and enters Pakistan near village Tadyal, Kot Naina, Tehsil Shakargarh. This river flows down about 560 km to join river Chenab near village Sayyal Faqir, Sidhnai, Tehsil Kabirwala. In addition to surface run-off up-stream water, it receives water from following link canals:

1. **Marala river link canal**
2. **Upper Chenab canal**
3. **Q. B. link canal**
4. **Trimu - Sidhnai link canal**

The stretch of river Ravi, i.e. from Baloki headworks to Sidhnai barrage has three main tributaries discharging water into the river, carry effluents emanating from different cities are:

1. **Degh nulla (2nd)**

   It comprises the following drains:

   i) Chichokimallian drain

   ii) Barianwala drain

   iii) Jaranwala - Sangla main drain

i) Chichokimallian Drain:

This drain receives wastes from different chemical and paper industries like Daud Hercules, Milk Pak Limited, Ali Paper Mills situated along Lahore Sheikhupura road.

STATION NO.	SAMPLING STATION	SITE
S1.	Baloki headworks	River
S2.	Syed wala	River
S3.	Mari pattan	River
S4.	Kamalia-Chichawatni (KC) bridge	River
S5.	Sidhnai barrage	River
T1.	Degh nulla	Tributary
T2.	Samundri main drain	Tributary
T3.	Sukhrawa main drain	Tributary

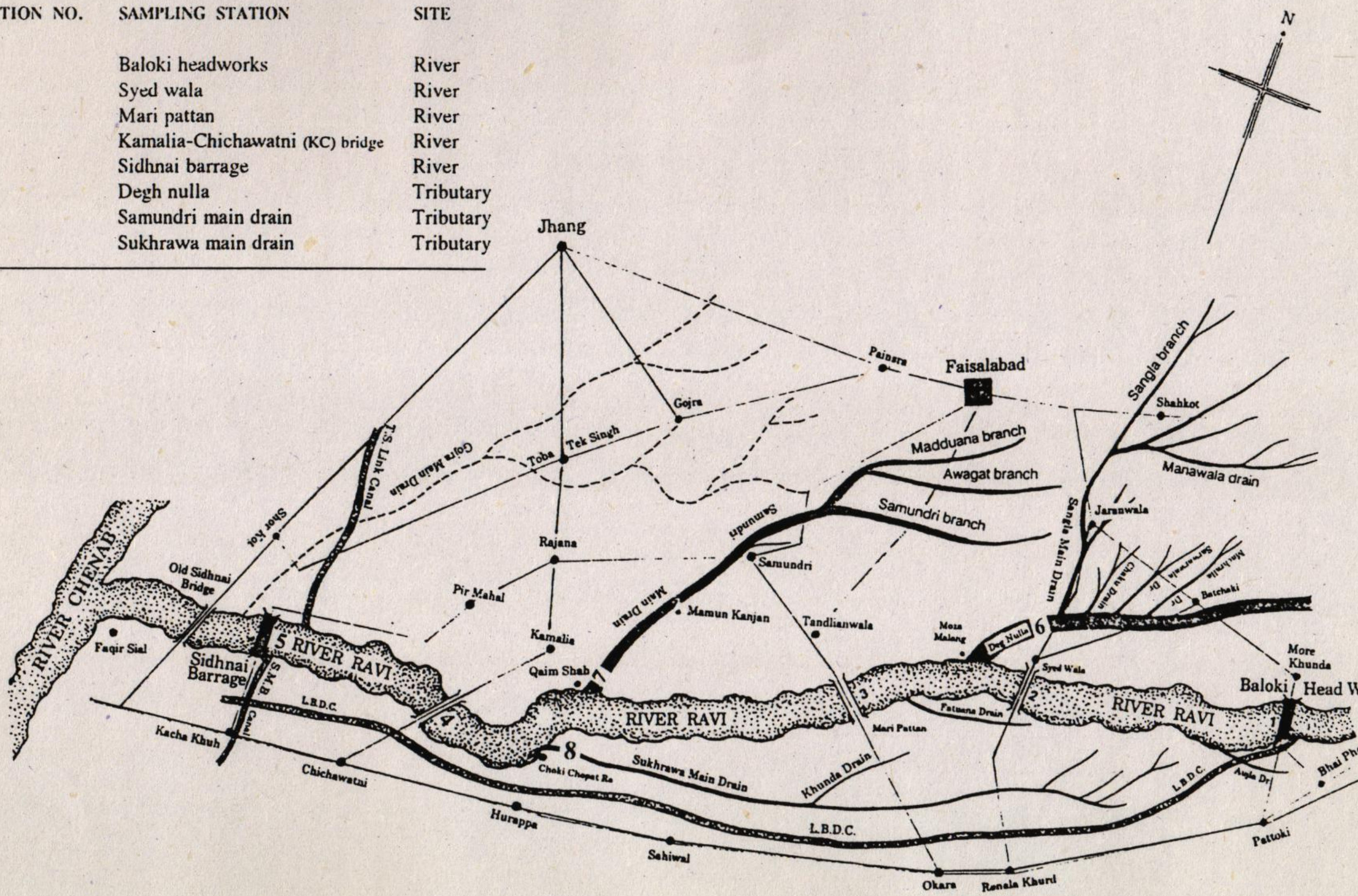


Figure: 2 Map of the study area from Baloki headworks to Sidhnai barrage.

ii) Barianwala Drain:

The Barianwala drain is an important tributary on Lahore - Sheikhupura road that receives effluents from major industries like I.C.I. Polyester, Rupali polyester, Suraj Ghee Mills, Bahawalpur, Premier, Ghazi, Qadria, Sampak paper Mills and many small industries. Barianwala drain, after receiving industrial and domestic discharges falls into Chichookimallian drain. Chichokimallian drain at Mudike assumes the name Degh nulla where it crosses Q. B. link canal through siphon. This drain also receives water from following small drains:

- i. **Machrala drain**
- ii. **Sarwarwala drain**
- iii. **Chaku drain**

iii) Jaranwala - Sangla Main Drain

The Degh nulla (2nd) also receives bulk discharges of water from Jarannwala - Sangla main drain which consists of following three streams:

- i. **Sangla branch**
- ii. **Manawala drain**
- iii. **Jaranwala branch**

These small drains after receiving domestic and industrial effluents from Sangla Hills, Manawala, Bechakee and Jaranwala falls into Jaranwala - Sangla main drain.

2. Sammundri Main Drain

It receives water from the following small tributaries:

- i) **Madduana branch**
- ii) **Awagat branch**
- iii) **Sammundri branch**

Madduana drain originates near village Madduana, Sangla Hills, receives domestic sewage, and falls into Sammundri main drain. Sammundri main drain after receiving municipal wastes from Madduana, Awagat and Sammundri disposal drains, falls into river Ravi near village Qaim Shah, Kamalia.

3. Sukhrawa Main Drain

Sukhrawa main drain discharges water (at the left bank of river) into the river near village Choki Chopat Ra. This drain receives municipal and industrial waste water from Renala Khurd, Okara, Sahiwal and Hurappa.

SECOND AND THIRD YEARS OF THE PROJECT:

STUDY AREA : From Baloki headworks to Sidhnai barrage (Figure 2)

DURATION OF WORK : 24 Months (from May 02, 1999 to April 30, 2001)

The following stations were studied at the river stretch from Baloki headworks to Sidhnai barrage for the collection of water, plankton, sediments and fish samples during the second and third years of the project:

River Site Sampling Stations:

Baloki headworks	(R1)
Syed wala bridge	(R2)
Mari Pattan bridge	(R3)
Kamalia-Chichawatni (K.C. bridge)	(R4)
Sidhnai barrage	(R5)

Effluent Discharging Tributaries:

Degh nulla (2nd)	(T1)
Sammundri main drain	(T2)
Sukhrawa main drain	(T3)

Procedure for sample collection:

Water, plankton and sediment samples, from all the above mentioned stations, during the whole study period, were collected on fortnightly basis to study the following parameters:

Metals:

1.	Iron	2.	Zinc
3.	Lead	4.	Nickel
5.	Manganese		

Physico-chemical variables:

1. Water temperature
2. Dissolved oxygen
3. pH
4. Electrical conductivity
5. Total hardness
6. Magnesium

1. Collection of Water Samples:

Water samples were collected in the morning hours between 9:00 a.m. to 12:00 noon. 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 six sub-stations, three at each right and left banks, at equal distances from the coming source (within the diameter of 100m).

Water temperature, dissolved oxygen, pH, and electrical conductivity were determined through meters, viz. HANNA HI-8053, HI-9143, HI-8520 and HI-8733 respectively. However, total hardness and magnesium were analyzed through the method described in A.P.H.A.(1971). Zinc, iron, manganese, lead, and nickel concentrations in water were determined through Atomic Absorption Spectrophotometer, by following method Nos. 3500-Zn B, 3500-Fe B, 3500-Mn B, 3500-Pb B, 3500-Ni B respectively (S.M.E.W.W.,1989).

2. Collection of Plankton Samples:

Plankton samples were collected on fortnightly basis by filtering nearly 50-60 liters of water through plankton net with a pore width of about 10 micrometer. For determining the frequency and percentage of different groups and different species of algae, the drop method of Venkateswarlu (1969) was adopted. In case of benthic algae number of individuals under high power field of the microscope were recorded and density of different groups calculated.

3. Collection of Sediment Samples:

Sediment samples were collected on fortnightly basis. Each sampling station was divided into three sub-sampling stations within a diameter of 100 m by following the proportionate sampling procedure. Samples were collected with the help of a iron pipe (dia = 2 inches) pressed with pressure through the water column to obtain a sediment layer of about one foot. Sediment samples collected from the three sub-sampling stations, at each of the station, were mixed to have a composite sample.

4. Collection of Fish Samples:

Fish samples were collected from the river on monthly basis at the following stations:

River Stretch	Year	Sampling Stations
From Shahdera to Baloki headworks	First	1. Shahdera bridge 2. Baloki headworks
From Baloki headworks to Sidhnai barrage	Second	1. Baloki headworks 2. Sidhnai barrage
From Baloki headworks to Sidhnai barrage	Third	1. Baloki headworks 2. Sidhnai barrage

Determination of Heavy Metals in Fish, Plankton and Sediment Samples:

Different organs of fish, viz. kidney, liver, gills and muscle were taken from the sampled fish during first and second years while fish scale, skin, muscle, gills, liver and kidney were analyzed for metals toxicity during the third year of the project. After wet digestion of the samples in Perchloric and Nitric acids, the volumes were prepared for the detection of heavy metals, viz. zinc, iron, manganese, lead and nickel through the methods of S.M.E.W.W. (1989) as described above. The metal concentrations in plankton samples were also determined on dry weight basis. Dry biomass of plankton were digested in Perchloric and Nitric acids and metal concentrations were determined by the Atomic Absorption Spectrophotometer through the methods of S.M.E.W.W. (1989) as mentioned above. The samples of sediments for heavy metals determination by Atomic Absorption Spectrophotometer were prepared according to Parker (1972), Harding and Whitton (1981) and S.M.E.W.W. (1989) methods.

Statistical Analyses of Data:

Data were statistically analyzed through two-way classification (Factorial Experiment) by following Steel and Torrie (1986). Analysis of variance and Duncan's Multiple Range tests were performed to find-out statistically significant differences among various parameters under study. Correlation and regression analyses were performed to find-out relationships / trends among various parameters under study.

RESULTS

METALS ECO-TOXICITY OF THE RIVER STRETCH FROM SHAHDERA TO BALOKI HEADWORKS

(First Phase of Project "One Year Data")

Metals in Water, Sediments and Plankton:

One year data on the status of river Ravi aquatic ecosystem regarding metal toxicity of water, sediments and plankton were collected and statistically analyzed. The mean annual concentrations of heavy metals and values for physico-chemical variables are presented in Appendix Tables 1 and 2 for the river sites and effluent discharging tributaries, respectively.

i. Zinc

Mean water zinc concentrations in all the tributaries fluctuated significantly within maximum concentration of 3.92 $\pm$ 2.04 mg L^{-1} in Furrukhabad nulla and minimum at Degh fall (0.50 $\pm$ 0.14 mg L^{-1}). However, there was non-significant difference between Munshi Hospital and Taj Company nullas. Among the river sampling sites, the mean zinc concentration in water at Sharqpur (R3) was the highest (0.88$\pm$ 0.45 mg L^{-1}) while the lowest at Shahdera bridge (Table 1). Statistical analysis shows that the effluent discharges from all the tributaries into the river significantly increased the zinc in river water at Baloki headworks. Zinc concentration in sediments was significantly high in Furrukhabad nulla (406.50 $\pm$ 34.67 μg g^{-1}) also. The river at Sharqpur exhibited significantly higher zinc in sediments (133.60 $\pm$ 28.95 μg g^{-1}) than rest of the river stretch. Plankton at Hudiara showed significantly higher zinc followed by that at Taj Company and Farrukhabad nullas. However, the difference between these two tributaries was non-significant. The river at Sharqpur had significantly higher mean metal concentration of 141.80 $\pm$ 11.25 μg g^{-1} than rest of the river stretch. However, the mean annual planktonic zinc at Baloki headworks was significantly higher (102.67 $\pm$ 5.20 μg g^{-1}) than that at Shahdera bridge (82.96 $\pm$ 13.28 μg g^{-1}).

ii. Iron

The mean iron concentrations in tributary water varied between a maximum of 11.89 $\pm$ 6.04 mg L^{-1} at Farrukhabad nulla and the minimum of 3.24 $\pm$ 1.01 mg L^{-1} at Hudiara. The difference between the mean iron concentrations at Taj Company nulla and Hudiara were statistically non-significant (Table 2). In the river stretch, Thatta polian wala showed maximum mean iron concentration of 7.81 $\pm$ 1.78 mg L^{-1} followed by the concentration of 7.42 $\pm$ 3.57 mg L^{-1} at Baloki headworks which was significantly higher than 6.84 $\pm$ 2.70 mg L^{-1} observed at Shahdera bridge. The most iron polluted bottom sediments were recorded at Furrukhabad nulla (24260.15 $\pm$ 871.50 $\mu g\ g^{-1}$) followed by Munshi Hospital nulla (13820.92 $\pm$ 200.01 $\mu g\ g^{-1}$) with significant difference between them. Both Taj Company nulla and Degh had significantly lowest iron concentrations in sediments. (Table 2). Among the river sampling sites, Barraderi appeared to be the most iron polluted site having mean iron concentration of 18200.25 $\pm$ 205.83 $\mu g\ g^{-1}$ while the same was minimum at Shahdera bridge (14580.10 $\pm$ 240.62 $\mu g\ g^{-1}$). The plankton samples collected from Farrukhabad nulla showed significantly higher mean iron content of 7351.00 $\pm$ 194.65 $\mu g\ g^{-1}$. Degh fall had significantly minimum planktonic iron (2300.55 $\pm$ 35.92 $\mu g\ g^{-1}$). In the river, Thatta polian wala presented the most iron polluted planktonic mass.

iii. Manganese

The mean manganese concentrations in tributary water varied between a maximum of 3.07 $\pm$ 0.66 mg L^{-1} (at Furrukhabad nulla) and minimum as 1.05 $\pm$ 0.17 mg L^{-1} at Bakar Mandi nulla. In the river, Baraderri had the mean maximum metal concentration of 1.42 $\pm$ 0.44 mg L^{-1} while the lowest at Thatta polian wala (0.89 $\pm$ 0.29 mg L^{-1}). Although the mean concentration of manganese at Baloki headworks was higher (0.78 $\pm$ 0.28 mg L^{-1}) than that at Shahdera (0.72 $\pm$ 0.37 mg L^{-1}) but the difference between them was statistically non-significant. Sediments at Munshi Hospital nulla contained the maximum manganese (3536.40 $\pm$ 300.37 $\mu g\ g^{-1}$) while the minimum at Degh fall (2471.92 $\pm$ 190.36 $\mu g\ g^{-1}$). However, the difference between Bakar Mandi nulla and Degh was non-significant. River stations showed significant differences for the concentrations of this metal in sediments. The maximum sediment contamination was recorded at R5 (I/B Q. B. link canal and Baloki headworks) having the mean concentration of 2188.29 $\pm$ 79.63 $\mu g\ g^{-1}$. Plankton at Farrukhabad nulla, Taj Company nulla and Hudiara had the maximum metal, however, the differences among these tributaries were statistically non-significant (Table

3). Thatta polian wala showed maximum planktonic manganese (482.60 $\pm$ 21.21 $\mu g\ g^{-1}$) while significantly minimum (220.50 $\pm$ 10.35 $\mu g\ g^{-1}$) at Shahdera.

iv. Lead

Lead in water fluctuated significantly among tributaries and river sampling stations. Among the tributaries, Farrukhabad nulla had the mean annual maximum lead concentration of 0.83 $\pm$ 0.29 mg L^{-1} followed by the concentration at Baker Mandi nulla. The mean lowest concentration of this metal was recorded at Degh fall (0.54 $\pm$ 0.16 mg L^{-1}). In river, Sharqpur had the mean highest concentration of 0.67 $\pm$ 0.25 mg L^{-1} while the same was lowest (0.25 $\pm$ 0.05 mg L^{-1}) at Shahdera. Lead in both plankton and sediments were the highest at Farrukhabad nulla as 378.80 $\pm$ 34.87 and 11.18 $\pm$ 4.05 $\mu g\ g^{-1}$ respectively. Both plankton and sediments in the river at Thatta polian wala and Sharqpur showed significatly higher metals as 225.00 $\pm$ 11.06 and 9.55 $\pm$ 3.94 $\mu g\ g^{-1}$ respectively than the other sites (Table 4).

v. Nickel

Nickel concentrations in water fluctuated significantly among all the tributaries. The maximum mean concentration of nickel was recorded at Farrukhabad nulla (2.43 $\pm$ 0.27 mg L^{-1}) which was significantly higher than rest of the tributaries. The minimum nickel contamination was recorded at Degh (0.69 $\pm$ 0.18 mg L^{-1}). All the river sites showed significant differences for nickel contamination except between Baradarri and Baloki headworks. River stretch at Sharqpur was highly polluted with nickel (0.75 $\pm$ 0.35 mg L^{-1}). Baloki water showed significantly higher concentrations of nickel than at Shahdera. Nickel in sediments showed almost similar trend as that of water. Farrukhabad nulla had the highest mean concentration of 863.04 $\pm$ 4.37 $\mu g\ g^{-1}$ and the lowest at Munshi Hospital nulla. The discharge of nickel from the tributaries into the river increased the metal concentration significantly at Baloki headworks (Table 5). Plankton collected from Hudiara showed the highest mean nickel content of 15.95 $\pm$ 6.11 $\mu g\ g^{-1}$ while the lowest at Degh fall (8.06 $\pm$ 1.38 $\mu g\ g^{-1}$). The river at Sharqpur presented the highest metal concentration in planktonic mass (9.24 $\pm$ 3.01 $\mu g\ g^{-1}$). Plankton at Baloki headworks had significantly higher metal than at Shahdera.

Physico-chemistry of Water:

i. Water temperature

The mean water temperatures in Farrukhabad, Taj Company and Baker Mandi nullas were significantly higher than rest of the tributaries. However, the differences among T2 v/s T2 and T3 v/s T1, T2, T4 and T5 were statistically non-significant (Table 6). The river water temperature values at all the sampling stations, except R5, were non-significantly different. The water in all the tributaries showed significantly higher mean temperature than the river water.

ii. Electrical conductivity

In tributaries, electrical conductivity of water fluctuated between a maximum of 1983.04 $\pm$ 262.20 μS (at Hudiara) and minimum of 1038.30 $\pm$ 159.56 μS at Farrukhabad nulla (Table 6). In river the water electrical conductivity values fluctuated significantly throughout the stretch under study, however, the difference between Shahdera and Baloki headworks was non-significant. The electrical conductivity of tributaries water was 3.10 times higher than that of the river water.

iii. Dissolved oxygen

Water in Degh fall showed significantly higher dissolved oxygen concentration of 3.28 $\pm$ 0.58 mg L^{-1} than rest of the tributaries. The mean minimum dissolved oxygen was recorded at Farrukhabad nulla (0.97 $\pm$ 0.43 mg L^{-1}). In the river, mean dissolved oxygen at R5 was the maximum followed by the concentration of 7.27 $\pm$ 0.45 mg L^{-1} at Shahdera while 5.64 $\pm$ 0.35 mg L^{-1} remained the lowest mean concentration at Thatta polian wala (Table 6).

iv. pH

In tributaries, the water pH fluctuated between a maximum of 8.35 $\pm$ 0.37 (at Hudiara) and a minimum of 7.31 $\pm$ 0.27 (at Taj Company nulla). The differences among T1, T2 and T4 were statistically non-significant (Table 7). The mean water pH throughout the river stretch was above 8. Baloki headworks showed significantly higher pH (8.32 $\pm$

0.16) which showed non-significant difference with R4 and R5. River water presented significantly higher pH values than the tributary water.

v. Total hardness

Total hardness of water fluctuated significantly among all the tributaries with the maximum mean hardness value of 491.80 $\pm$ 50.41 mg L^{-1} at T5 (Hudiara nulla). In the river, Thatta polian wala had the mean highest water hardness of 222.80 $\pm$ 46.22 mg L^{-1} while the minimum at Shahdera bridge. Water at Shahdera was significantly softer than rest of the river sites (Table 7).

iv. Magnesium

Hudiara nulla showed significantly higher mean magnesium concentration of 36.48 $\pm$ 6.01 mg L^{-1} than rest of the tributaries (Table 7). The magnesium contents of water in the river decreased significantly downstream as the lowest mean magnesium was recorded at Baloki headworks (9.27 $\pm$ 0.81 mg L^{-1}) and the highest at Baradarri (12.90 $\pm$ 2.55 mg L^{-1}).

Metals Toxicity of River:

Mean annual concentrations of all the heavy metals except zinc in he water of six effluent discharging tributaries were significantly higher than the safe limits set by the EPA (Pakistan) for Municipal and liquid industrial effluent discharges. However, the water throughout the stretch of river was not suitable for aquatic life, freshwater fisheries and drinking purposes as described by EPA, USA (Tables 1 - 6 and 8).

Relationships Between Metals Eco-toxicity and Physico-chemical Variables:

Table 9 shows the final step equations for the regression of metal ion toxicity of water, sediments and plankton on physico-chemical variables. The accumulation of zinc in water, sediments and plankton were dependent positively ($p < 0.01$) upon water temperature. However, dissolved oxygen showed negatively significant regression on both sedimental and planktonic zinc. Iron accumulation in water was negatively ($p < 0.01$) dependent upon electrical conductivity and dissolved oxygen. However, the regression coefficient for water hardness was positively significant at P < 0.01. Manganese in water showed the same trend as that of iron. This relationship explains 91.58 percent variations for this metal in water. The accumulation of manganese in sediments was 88.89 percent dependent upon electrical conductivity, pH and temperature. However, the partial regression coefficients for both pH and temperature were negatively significant while hardness showed positively significant regression on planktonic manganese. Lead accumulations in water, sediments and plankton were negatively (p<0.01) dependent upon dissolved oxygen. Water temperature along with dissolved oxygen showed significant regression on lead in water. Nickel in water was 46.48 percent dependent upon water temperature. The regression coefficient for this regression model was positively significant. The accumulation of nickel in sediments was negatively (p< 0.01) dependent upon dissolved oxygen. This relationship explains 65.47 percent variations in sedimental nickel were due to dissolved oxygen. However, total hardness was the only variable that had 74.78 percent contribution towards planktonic nickel. The regression coefficient for this variable was positively significant at p< 0.01.

Table 10 shows the trends of metallic ion flow among water, sediments and plankton. There was positively significant correlation between plankton and sediments for the accumulation of zinc. The accumulations of zinc, iron, manganese, lead and nickel were positively (p< 0.01) dependent upon metal ions in sediments. The uptake and accumulation of zinc, iron, lead and nickel in sediments were positively (p< 0.01) dependent upon metal concentrations in water while manganese in sediments had positively significant dependence on planktonic metal and this regression model explains 79.82 percent variations for manganese concentration in sediments.

Planktonic Productivity:

Appendix Table 3 shows the mean annual productivity values for both phytoplankton and zooplankton in the tributaries and river water. Among phytoplankton, *Aphanocapsa, Bacillaria, Closterium, Cyclotella, Cocconeis, Cosmarium, Denticulla, Dinobryon, Euglena, Gloeocapsa, Pinnularia, Spirulina* and *Spirogyra* showed considerable tolerance against heavy metals toxicity both in tributaries and river. However, the genus, viz. *Anabaena, Arthrosira, Chlorella, Fragilaria, Frustulia, Melosira,* *Microcystis, synedra, Scenedesmus, Volvox* and *Zygnema* were almost absent at highly polluted sites. Among the zooplankton, *Brachionus* and *Polyarthra* were absent in all the tributaries while showed their presence in the river significantly. *Keratella, Cyclops, Monnstyla* and *Filinia* were the sensitive forms and showed their existence according to the severity of pollution at different sites.

Impact of Metal Toxicity on Fish:

Tables 11 - 15 show the concentrations of zinc, iron, manganese, lead and nickel in different organs of three fish species, viz. *Catla catla, Labeo rohita* and *Cirrhina mrigala* captured from Shahdera and Baloki headworks. Analysis of variance shows highly significant differences among fish organs (muscle, gills, liver and kidney) for the accumulation of all the heavy metals. However, three fish species showed non-significant differences for the pattern of metals, viz. zinc, iron and nickel accumulations in their bodies (Table 16). Fish liver accumulated significantly higher quantities of all metals than the other organs. The patterns of zinc accumulations in fish muscle, gills and kidney were statistically non-significant. There was non-significant difference between fish gills and kidney for the contamination of iron while the metal concentration was significantly lowest in fish muscle. Manganese and nickel were significantly lowest in muscle while lead in gills and liver were non-significantly high in fish muscle and kidney.

There were non-significant differences among three fish species for the pattern of zinc, iron and nickel accumulations. However, *Catla catla* showed significantly higher tendency to accumulate both manganese and lead in its body. The manganese levels in both *Labeo rohita* and *Cirrhina mrigala* were statistically at par. Among the three fish species, *Cirrhina mrigala* had significantly lesser tendency to accumulate lead in its body than *Catla catla* and *Labeo rohita* (Table 16).

Relationships Among Water, Sediments, Plankton and Fish for the Accumulation of Heavy Metals:

Table 17 shows the correlation coefficients among water, sediments, plankton and fish for the uptake and accumulation of heavy metals. The relationships among water, plankton and sediments were positively significant for the accumulation of zinc. Metal contamination in fish body showed non-significantly positive correlation with metal ions in water, plankton and sediments. The correlation coefficients among water, plankton and sediments were significantly positive for the accumulation of iron. Iron concentrations in fish body showed negative but non-significant correlation with water and sediments. Sediments and plankton showed direct (significantly positive) relationship for the flow of manganese in aquatic habitat. However, the other relationships, i.e. plankton v/s water and sediment v/s water and fish body were negatively non-significant. Lead in all the variables except between fish body and plankton showed non-significantly negative correlation among them. Nickel in sediments showed significantly positive correlation with the metal ion concentrations in both water and plankton while fish body had negative correlation with water, plankton and sediments. The correlation coefficient between fish body and sediment was significant.

METALS ECO-TOXICITY OF THE RIVER STRETCH FROM BALOKI HEADWORKS TO SIDHNAI BARRAGE

(Second Phase of the Project "Two Years Data")

Two years data for heavy metals in water, sediments and plankton and physico-chemistry of the river stretch from Baloki headworks to Sidhnai barrage, at various river site sampling stations and effluent discharging tributaries are presented in Appendix Table 4.

i. Iron

The levels of iron in river water fluctuated between a maximum mean concentration of 8.71 $\pm$ 3.72 mg L^{-1} (at Baloki headworks) and minimum as 6.00 $\pm$ 1.77 mg L^{-1} (at K.C. bridge). The difference between these two sampling stations, for the toxicity of iron, was statistically significant. All the sampling stations showed significant differences for the fluctuations of this metal in water. Among the effluents discharging tributaries, Degh nulla exhibited significantly higher mean concentration of iron in water than Sammundri and Sukhrawa main drains as 9.85 $\pm$ 2.25 and 7.48 $\pm$ 0.78 mg L^{-1}, respectively. The differences among all the three tributaries for the toxicity of iron was statistically significant (Table 18). The mean concentration of iron (9.60 $\pm$ 1.66 mg L^{-1}) during second year was significantly higher than the first year mean value of 4.97 $\pm$ 0.54 mg L^{-1} computed for the whole stretch of river under investigation.

The mean iron concentration in bed sediments of the river showed non-significant differences among Baloki headworks, Syadwala and Mari Pattan. However, the concentration of this metal changed significantly at K. C. bridge (16921.95 $\pm$ 4177.06 $\mu g\ g^{-1}$). Sidhnai barrage showed significantly lower iron contamination than at K. C. bridge but was significantly higher than rest of the river site sampling stations. The sediments collected during second year showed significantly higher mean iron concentration of 18696.50 $\pm$ 1599.66 $\mu g\ g^{-1}$ than that of first year (11681.64 $\pm$ 1201.28 $\mu g\ g^{-1}$). Sukhrawa main drain showed significantly highest iron in sediments (23754.10 $\pm$ 7672.15 $\mu g\ g^{-1}$) while the same was lowest as 15218.77 $\pm$ 1961.60 $\mu g\ g^{-1}$ at Sammundri main drain. All the three effluent discharging tributaries exhibited significant differences for the contamination of sediments with iron. However, iron contamination was significantly higher during the second year than the first year (Table 18).

The plankton collected from Baloki headworks had the mean highest iron concentration of 7993.95 $\pm$ 4901.49 $\mu g\ g^{-1}$ at Baloki headworks while the same was minimum as 3078.63 $\pm$ 2076.63 $\mu g\ g^{-1}$ at Syedwala. The differences among all the river site sampling stations, for metal contamination of plankton, were statistically significant. However, the plankton collected during the second year had significantly higher metal contamination of 8151.06 $\pm$ 2707.64 $\mu g\ g^{-1}$ than the plankton samples collected during first year which had the mean iron concentration of 2587.21 $\pm$ 966.82 $\mu g\ g^{-1}$. Among the three effluent discharging tributaries, Sammundri main drain had the mean highest iron in plankton samples followed by Degh nulla and Sukhrawa main drain having the mean concentrations of 10488.36 $\pm$ 6370.69 , 7199.94 $\pm$ 3261.68 and 3744.10 $\pm$ 833.38 $\mu g\ g^{-1}$ respectively. The iron concentrations in plankton increased significantly during second year of the data collection (Table 18).

ii. Zinc

Mean zinc concentration in water was the maximum (2.58 $\pm$ 0.12 mg L^{-1}) at Mari Pattan, followed by that of 2.35 $\pm$ 0.54 mg L^{-1} at Sidhnai barrage. The difference between these two sampling stations was statistically significant. However, K. C. bridge had the mean lowest zinc in water as 2.25 $\pm$ 0.29 mg L^{-1}. The difference between K. C. bridge and Syedwala, for the contamination of water, was statistically at par. Zinc concentration in tributary water fluctuated significantly among all the tributaries with the mean highest contamination level of 3.27 ± 0.47 mg L^{-1} at Degh nulla, followed by that at Sammundri and Sukhrawa main drains with the mean concentrations of 3.01 ± 0.48 and 1.84 ± 0.03 mg L^{-1} respectively. The contamination of zinc in both river and tributary waters increased significantly during second year of data collection (Table 19).

The river bed sediments at Syedwala showed the mean highest contamination of zinc as 431.83 ± 35.70 $\mu g\ g^{-1}$ while the same was lowest at Baloki headworks (180.16 ± 12.59 $\mu g\ g^{-1}$). Among the tributaries, Sammundri main drain showed the mean highest zinc contaminated sediments (550.04 ± 370.43 $\mu g\ g^{-1}$), followed by that at Degh nulla and Sukhrawa main drain. However, the differences among all the three effluents discharging tributaries, for the contamination of sediments, were statistically significant. The contamination of zinc in sediments increased significantly during second year while decreased in tributary water significantly.

The contamination of plankton with zinc, throughout the stretch of river Ravi, showed variable response with the mean highest contamination at K. C. bridge (184.45 ± 105.07 $\mu g\ g^{-1}$) and minimum at Baloki headworks (148.98 ± 88.70 $\mu g\ g^{-1}$). The plankton at Sammundri main drain showed significantly higher tendency to accumulate zinc (with the mean zinc contamination level of 341.98 ± 268.97 $\mu g\ g^{-1}$) while the same was minimum at Degh nulla which showed the contamination level of 193.99 ± 122.87 $\mu g\ g^{-1}$. The plankton collected during first year from both river and tributaries had significantly lower tendency for the zinc accumulation than that during second year (Table 19).

iii. Lead

Mean lead toxicity levels in both river and tributaries, for the first and second years are presented in Table 20. The K. C. bridge showed mean highest metal in water as 1.88 ± 0.22 mg L^{-1} while the same was minimum at Baloki headworks which showed the mean lead toxicity of 0.53 ± 0.13 mg L^{-1} in water. The differences among all the river site sampling stations, for the contamination of water with lead, were statistically significant at $p < 0.05$. First year showed significantly higher lead contamination level in water than during second year of data collection. Among the tributaries, Degh nulla showed the highest lead contamination in water (1.25 ± 0.29 mg L^{-1}), followed by that in Sammundri and Sukhrawa main drains having the mean lead concentrations of 1.22 ± 0.30 and 1.01 ± 0.50 mg L^{-1} respectively. The differences among tributary waters for lead toxicity were statistically significant. Lead contamination level of water increased significantly during second year of the data collection.

Contamination of sediments with lead at Baloki headworks was the maximum while the same at K. C. bridge showed minimum mean values of 133.90 ± 2.11 and 49.44 ± 40.12 $\mu g\ g^{-1}$ respectively. The contamination levels fluctuated significantly among sampling stations. First year showed significantly higher mean contamination level than the second year. The sediments collected from all the three tributaries showed significantly variable toxicity levels of lead with the maximum at Sukhrawa main drain (136.82 ± 14.07 $\mu g\ g^{-1}$). The mean annual value for this variable was significantly lower during first year (Table 20).

The plankton collected from all the five river site sampling stations showed significantly variable lead contamination levels. However, the maximum contamination was recorded at Syedwala (23.92 ± 19.62 $\mu g\ g^{-1}$) while the same was the minimum at Sidhnai barrage (17.18 ± 12.67 $\mu g\ g^{-1}$). Among the tributaries, Degh nulla had the mean highest planktonic contamination of 24.06 ± 17.20 $\mu g\ g^{-1}$ while the lowest being recorded at Sammundri main drain (15.49 ± 8.63 $\mu g\ g^{-1}$). The plankton collected from both the river and tributary waters during second year showed significantly highest contamination level (Table 20).

iv. Nickel

Nickel in water fluctuated significantly throughout the stretch of river Ravi from Baloki headworks to Sidhnai barrage. However, the contamination levels fluctuated between a maximum of 1.75 ± 0.71 mg L^{-1} and a minimum mean value of 1.54 ± 0.55 mg L^{-1} at K. C. bridge and Sidhnai bridge respectively. Degh nulla had the mean highest nickel contamination level of 1.91 ± 0.85 mg L^{-1} while the same was significantly minimum as 1.81 ± 0.45 mg L^{-1} at Sukhrawa main drain. The contamination level of water increased significantly during second year (Table 21).

The nickel toxicity in bed sediments fluctuated significantly throughout the stretch with a maximum mean level of 208.49 ± 24.34 $\mu g\ g^{-1}$ at Syedwala while the same was minimum at K. C. bridge having the mean contamination level of 94.80 ± 67.48 $\mu g\ g^{-1}$. Sammundri main drain showed significantly higher nickel contamination in sediments than rest of the two tributaries. The mean contamination level of sediments in the river and tributaries were significantly higher during first year of data collection.

Mari Pattan appeared to be a station which showed significantly higher planktonic nickel concentration of 33.49 $\pm$ 29.85 $\mu g\ g^{-1}$, followed by that at K. C. bridge (32.76 $\pm$ 28.53 $\mu g\ g^{-1}$). Among the tributaries, Degh nulla had the mean highest nickel contaminated plankton, followed by that in Sukhrawa main drain having the mean contamination levels of 41.17 $\pm$ 34.16 and 34.19 $\pm$ 29.34 $\mu g\ g^{-1}$ respectively. The differences among all the three effluent discharging tributaries for nickel toxicity of plankton were statistically significant at $p < 0.05$. The contamination of plankton with nickel in both river and tributary waters increased significantly with the passage of time (Table 21).

v. Manganese

Manganese in river water fluctuated significantly. However, the contamination levels ranged between 5.02 $\pm$ 0.07 and 2.70 $\pm$ 0.72 mg L^{-1} at K. C. bridge and Baloki headworks respectively. Sammundri main drain showed the mean highest manganese contaminated water having the concentration of 4.83 $\pm$ 0.52 mg L^{-1} and the lowest 4.48 $\pm$ 0.07 mg L^{-1} in Sukhrawa main drain. Manganese contamination in the river water was the highest during first year of data collection.

Sediments at K. C. bridge showed the mean maximum contamination level of 1814.59 $\pm$ 575.15 $\mu g\ g^{-1}$ while the minimum at Syedwala as 1425.54 $\pm$ 47.91 $\mu g\ g^{-1}$. The differences for the contamination levels of sediments at five river site sampling stations were statistically significant except between Mari Pattan and Sidhnai barrage. The sediments collected from Sammundri main drain showed significantly higher contamination level than rest of the two tributaries. The contamination levels of both the river and tributaries increased significantly during second year (Table 22).

The plankton at Sidhnai barrage showed the mean highest manganese contamination of 449.58 $\pm$ 79.59 $\mu g\ g^{-1}$ while the same was lowest at Syedwala (374.38 $\pm$ 137.00 $\mu g\ g^{-1}$). Among the tributaries, Degh nulla and Sammundri main drain showed statistically non-significant differences for metal contamination levels of plankton. However, the plankton at Sukhrawa main drain had significantly lower tendency to accumulate manganese in their bodies than at Degh nulla and Sammundri main drain. The metal contamination of plankton in the river and tributaries increased significantly during second year of data collection.

Physico-chemistry of Water:

The mean annual data for first and second years, at the stretch from Baloki headworks to Sidhnai barrage, for the physico-chemical variables, viz. water temperature, pH, dissolved oxygen, electrical conductivity, total hardness and magnesium in the river and tributary waters are presented in Appendix Tables 4.

i. Water temperature

River water showed significantly higher mean temperature of 23.91 $\pm$ 0.06 °C at K. C. bridge, followed by that at Mari Pattan (23.68 $\pm$ 0.12 °C). However, the difference between these two sites was statistically non-significant. Both Baloki headworks and Syedwala exhibited significantly mean lowest water temperature of 22.38 $\pm$ 0.10 and 22.57 $\pm$ 0.12 °C respectively. However, the difference between them was non-significant (Table 23). All the three tributaries showed differential response for the temperature of water.The temperature being significantly highest in the Sammundri main drain (28.10 $\pm$ 0.04 °C), followed by that of Degh nulla and Sukhrawa main drain. The temperature of both river and tributary waters increased significantly during second year of the data collection.

ii. pH

There were statistically non-significant differences among all the river site sampling stations, except Syedwala, for pH of water. The highest concentrations of hydrogen ions were recorded at Mari Pattan and Baloki headworks. However, the water throughout the stretch, from Baloki headworks to Sidhnai barrage, of river Ravi was alkaline. Among the tributaries, the water in Sukhrawa main drain showed significantly higher alkalinity than Degh nulla. However, the difference between Sammundri and Sukhrawa main drains was statistically non-significant. In the tributary water, the mean pH increased significantly during second year while the same in the river water was significantly higher during first year.

iii. Dissolved oxygen

Dissolved oxygen of water showed significant variations throughout the stretch of river with the highest mean dissolved oxygen concentration of 6.96 ± 0.05 mg L^{-1} at Mari Pattan while the same was minimum at Baloki headworks (5.82 ± 0.12 mg L^{-1}). Among the three tributaries, Sammundri main drain had the lowest mean dissolved oxygen content of 0.24 ± 0.10 mg L^{-1}. The other two tributaries, viz. Degh nulla and Sukhrawa main drain showed mean dissolved oxygen concentrations of 1.07 ± 0.40 and 1.99 ± 0.07 mg L^{-1} respectively. The mean dissolved oxygen concentrations in the river water increased while that of tributary water decreased significantly during second year (Table 23).

iv. Electrical conductivity

The conductance of river water showed significant variations throughout the stretch of river under investigation. The maximum mean electrical conductivity 0f 798.88 ± 92.42 μS was recorded at K. C. bridge while the same remained significantly minimum at Baloki headworks (422.54 ± 34.62 μS). Degh nulla had significantly highest mean electrical conductivity of water (10568.77 ± 5950.54 μS) while the same was minimum at Sukhrawa main drain (2807.55 ± 503.04 μS). The electrical conductance in both the river stretch and tributary waters increased significantly during second year (Table 23).

v. Total hardness

The hardness of water fluctuated between a maximum of 180.58 ± 19.48 mg L^{-1} (at Mari Pattan) and minimum of 134.09 ± 10.42 mg L^{-1} (at Syedwala). Degh nulla showed significantly higher mean water hardness (914.28 ± 223.02 mg L^{-1}) than Sammundri and Sukhrawa main drains having the hardness of 453.56 ± 3.27 and 312.43 ± 17.18 mg L^{-1} respectively . The hardness increased significantly during second year in the tributary water while that in river decreased significantly (Table 23).

vi. Magnesium

The river water had the maximum and minimum mean magnesium at Mari Pattan and Syedwala as 137.53 ± 24.02 and 101.81 ± 15.18 mg L^{-1} respectively. The magnesium concentrations in all the tributaries fluctuated significantly. The highest mean magnesium in water was recorded at Degh nulla (867.98 ± 118.32 mg L^{-1}) which was statistically different from that of Sammundri and Sukhrawa main drains. The magnesium contents in both river and tributary waters decreased significantly during second year (Table 23).

Quality of River and Tributary Waters:

Table 8 shows water quality criteria for sustainable freshwater fisheries, aquatic life and environmental quality control standards for municipal and liquid industrial effluents described by EPA (USA and Pakistan). The Appendix Table 4 presents data for the contamination of water with different metals. The present metallic ions , viz. iron, zinc, lead, nickel and manganese loads in both river and tributary waters were significantly higher than the safe limits of these metals for sustainable conservation of aquatic life in freshwater.

Contribution of Tributary's Effluent Discharges Towards Metal Toxicity of River Water:

Table 24 shows the regression of metal's toxicity of river water on the metallic ion concentrations of tributary water. Iron in river water showed 62.86 percent dependence on the metallic ions in tributary water. The regression coefficient for this model was positive and statistically significant at $p < 0.01$. Zinc loads in tributary water contributed 76.37 percent towards contamination of this metal in the river. The regression coefficient for this model was positive and highly significant. This shows significant increase in the contamination level of river with the increasing trend of this metal in tributaries. The contribution of tributaries towards lead contamination in river water was 8.76 percent only. This shows positive but non-significant dependence of river toxicity on tributary water. The nickel contamination in river water showed positively significant dependence on tributary's metallic loads. The coefficient of determination (R^2) for this relationship was computed as 0.8660. The high value of R^2 for this equation predicts high precision of regression model. Tributary water appeared to be responsible for 45.17 percent variations in river water manganese concentrations. The regression coefficient for this regression model was positive and significant at $p < 0.05$.

Dependence of Metals Eco-toxicity of River and Tributaries on the Physico-chemistry of water:

i. Iron

Iron in both river and tributary waters showed negatively significant dependence on electrical conductivity of water, while, the same on water temperature was positive and significant at $p < 0.05$. However, coefficients of determination for the equations computed for river and tributary waters were 0.8673 and 0.5861 respectively. The accumulation of iron in the sediments of tributaries was negatively dependent on electrical conductivity. The accumulation of iron in plankton collected from the river had 47.59 percent dependence on electrical conductivity of water also. However, the regression coefficient for this relationship was negative and significant at $p < 0.05$. Plankton in tributaries showed 67.14 percent dependence on electrical conductivity and temperature for the accumulation of iron. The partial regression coefficients for both the variables, in the equation, were highly significant. The regression coefficient for electrical conductivity was negative while that of temperature remained positive (Table 25).

ii. Zinc

Both electrical conductivity and temperature of water were the variables which were responsible for 67.71 percent variations of zinc contamination in river water. The partial regression coefficient for electrical conductivity was negatively significant ($p < 0.05$) while that of temperature was positive and significant at $p < 0.01$. The accumulation of zinc in sediments was 45.26 percent dependent upon electrical conductivity and pH of water. However, the partial regression coefficient for electrical conductivity was positive ($p < 0.05$) while the same for pH was negative but highly significant. Plankton in the river showed 53.98 percent dependence on electrical conductivity of water for the accumulation of this metal. The relationship between planktonic zinc and electrical conductivity of water was negative and highly significant (Table 26). The contaminations of zinc in both water and plankton of tributaries were dependent inversely upon electrical conductivity of water. However, the partial regression coefficient for the regression equation, computed for water, was non-significant. Total hardness appeared to be another variable which showed direct relationship with the intensity of metallic ion pollutions in water and plankton. Water temperature showed positively significant relationship with metallic ions in water only. The

R^2 values for all the three regression equations, computed for metals in water, sediments and plankton, were ranged between 0.6124 and 0.7611 (Table 26).

iii. Lead

Lead contamination in river bed sediments showed 55.31 percent dependence on electrical conductivity, pH and water temperature. The partial regression coefficients for all the three variables were negatively significant at $p < 0.01$ except electrical conductivity. Lead contamination of plankton in river showed inverse but significant ($p < 0.05$) relationship with electrical conductivity of water. This regression model reveals more than 44 percent variations in planktonic lead toxicity due to electrical conductivity of water. In tributaries, both water and planktonic lead toxicities were negatively ($p < 0.01$) dependent upon electrical conductivity of water. However, lead toxicity in water increased significantly with the rise in water temperature also (Table 27).

iv. Nickel

Electrical conductivity and temperature of water were the variables responsible for 74.94 percent variations in river sediments for the uptake and accumulation of nickel. The partial regression coefficients for both the variables were positive and highly significant. The planktonic nickel in the river showed inverse but non-significant relationship with the electrical conductivity of water. In tributaries, water hardness, electrical conductivity and temperature had 61.81 percent responsibility for the nickel concentration in water. The partial regression coefficients for electrical conductivity was negatively significant ($p < 0.01$) while for temperature the same remained positive but non-significant. Electrical conductivity was the only variable which enhanced the nickel contamination in sediments. The toxicity of nickel in plankton increased significantly with the decrease of water electrical conductivity. The correlation coefficient for this regression model was - 0.7187 (Table 28).

v. Manganese

The manganese contaminations of water and plankton were dependent positively on temperature of water. However, the introduction of electrical conductivity along with water temperature in the regression equation increased the R^2 value up to 0.7108. The partial regression coefficient for electrical conductivity was negative but highly significant. In tributaries, contamination of water increased significantly with the increase in total hardness and temperature of water. Therefore, this regression model predicts more than 70 percent of the variations in manganese due to total hardness and temperature. The contamination of sediments increased significantly with the increase in electrical conductivity while decreased with declining dissolved oxygen of water. Planktonic toxicity showed 59.78 percent dependence on total hardness and electrical conductivity of water. However, the partial regression coefficient for total hardness was positive while for that of electrical conductivity remained negative but highly significant (Table 29).

Relationships Among Water, Sediments and Plankton for the Uptake and Accumulation of Metals:

Table 30 shows positive but non-significant dependence of iron, zinc and manganese toxicity of sediments on metallic ions in water while both lead and nickel in sediments showed negative but non- significant regression on metallic ions in water. In tributaries, iron, lead and manganese had positive while zinc and nickel showed negative and non-significant dependence on metallic ions in water. Both iron and nickel contaminations in plankton were responsible directly ($p < 0.01$) on metallic ions in river water. In tributaries, all the metals in plankton showed direct relationship with the intensity of metallic ions in water. However, the regression coefficients for iron, lead and nickel were significant (Table 31).

The uptake and accumulation of iron in plankton was positively and significantly dependent upon metallic ions in sediments while the same for nickel uptake was negative but significant at $p < 0.05$. The regression coefficients for both lead and manganese were negative and non-significant (Table 32). The plankton in tributary water showed 58.87 percent dependence upon iron in sediments. The regression coefficient for this model was highly significant. However, the same for zinc was negative and highly significant. The uptake and accumulation of lead in plankton was 45.84 percent dependent upon metal pollution in bed sediments. The regression coefficient for this equation was positive and significant at $p < 0.05$. The same for nickel and manganese were negative and non-significant (Table 32).

Flow of Metals in the River and Tributary's Ecosystems:

The flow patterns of five metals, viz. iron, zinc, lead, nickel and manganese have been studied in both the river and tributaries water, plankton and sediments by using the step-wise regression method (Table 33).

i. River ecosystem:

First equation gives the regression of iron toxicity in plankton on contamination level of this metal in river bed sediments. This relationship explains more than 44 percent variations in metal toxicity of plankton. The partial regression coefficients for this relationship was positive and highly significant. At step-2, the introduction of iron in water increased the R^2 value up to 0.7777. The partial regression coefficient for both sediments and water were positive and highly significant. Nickel contamination in plankton showed positively significant dependence on the metallic ions in water and this relationship explains more than 77 percent variations in the uptake and accumulation of nickel in plankton. The variables, viz. zinc, lead and manganese did not meet the criteria of step-wise regression analysis.

ii. Tributary ecosystem:

The regression equation computed to determine the flow of iron from sediments to plankton showed significantly positive increase of iron accumulation in plankton due to increase in metal toxicity in sediments. This relationship shows more than 58 percent dependence of planktonic iron due to sediment toxicity. At step-2, the introduction of iron toxicity in water along with sediments increased the R^2 value by 0.2519. Both the regression coefficients for the variables, in the regression equation, were positive and highly significant. Zinc in plankton showed significantly inverse relationship with the contamination level of sediments. This relationship predicts more than 61 percent contribution of zinc toxicity in sediments towards accumulation of this metal in plankton. At step-2, the introduction of zinc toxicity in water along with sediments exerted positive but non-significant influence on the uptake and accumulation of this metal by the plankton. The regression equation computed for lead toxicity in plankton showed positively significant relationship with the contamination level of water. Step-2, explains 58.73 percent variations in lead toxicity of plankton due to contaminated sediments and water.

Nickel in water was the only variable that contributed 63.03 percent towards metallic ions toxicity in plankton. However, both these variables showed positively significant relationship with each other. In case of manganese no variables meet the criteria of step-wise regression method (Table33).

PLANKTON AS AN INDEX OF METAL POLLUTION IN THE RIVER RAVI

i. First year at the River Stretch from Baloki headworks to Sidhnai Barrage:

Appendix Table 5 shows the planktonic productivity indices of river Ravi and effluent discharging tributaries under investigation. Thirty-two genera of phytoplankton while fourteen genera of zooplankton have been identified from the water samples collected throughout one year of study period. Among phytoplankton, *Aphanothece, Bumilleria, Cyclotella* and *Spirulina* showed considerable tolerance against metal pollution both in river and tributary waters. However, among phytoplankton the genus *Arthgrospira, Bacillaria, Cladophora, Chlorella, Cosmarium, Eudorina, Microcystis, Oscillatoria, Pandorina, Scendesmus, Spirulina* and *Trachilomonas* were almost absent in all the three effluent discharging tributaries. Among zooplankton, *Asplanchna, Brachionus, Canthocamptus, Diaptomis* and *Moina* showed their absence in the tributary water also. The genus *Aphanocapsa, Navicula, Oocystis, Pendiastrum, Peridinium, Phacus* and *Polyarthra* appeared to be sensitive against heavy metals pollution. However, the occurrence of genus *Anabaena, Arthrospira, Euglena, Melosira, Synedra, Spirogyra, Volvex, Bosmina, Daphnia* and *Monnstyla* correlated with the intensity of metallic ion pollution in both water and sediments.

ii. Second year at the River Stretch from Baloki headworks to Sidhnai Barrage:

Appendix Table 6 shows the mean annual distribution of plankton in effluent discharging tributaries and at various sites of river stretch from Baloki headworks to Sidhnai barrage. Myxophyceae, Bacillariopgyceae and Chlorophyceae were the important groups distributed in the river throughout the period of study. Among phytoplankton, *Aphanocapsa, Bumilleria, Bacillaria, Cladophora, Cocconeis, Eudorina, Microcystis, Pandorina, Scendesmus, Volvox* and *Zygnema* indicated direct relationship with the intensity of pollution as these genera were almost absent in highly polluted tributaries. However, the genus, viz. *Aphanothece, Anabaena, Arthrospira, Cyclotella, Denticulla, Dinobryon, Euglena, Navicula, Peridinium. Phacus* and *Synedra* showed considerable tolerance against heavy metal pollution. Among zooplankton, *Asplanchna, Brachionus, Canthocamptus, Cyclops, Diaptomus, Moina* and *Polyarthra* were almost absent at highly polluted sites. However, the genus, viz. *Bosmina, Filinia, Keratella* and *Monnstyla* showed considerable tolerance against metallic ion pollution. *Daphnia* appeared to ba a sensitive form against metal pollution in water.

FISH AS A BIO-INDICATOR OF FRESHWATER CONTAMINATION BY METALS

i. First year at the River Stretch from Baloki headworks to Sidhnai Barrage:

Data on the accumulation of iron, zinc, lead, nickel and manganese in fish organs, viz. muscle, gills, liver and kidney are presented in Tables 34-38. Three fish species, viz. *Catla catla, Labeo rohita* and *Cirrhina mrigala* captured from Baloki headworks and Sidhnai barrage were examined for their metallic ion concentrations. There existed highly significant differences among the fish organs for the accumulation of all the heavy metals. However, fish species showed non-significant differences for the accumulation patterns of all metals, except lead. Site of fish collection exerted significant effect on the bio-accumulation of iron and lead in fish body also. The fish procured from Baloki headworks had significantly higher iron and nickel in their bodies. Accumulation of iron in all the four organs showed statistically significant differences (Table 39). However, the accumulation of zinc in fish muscle and gills and, gills v/s kidney were statistically non-significant. Lead accumulations in both gills and liver were significantly higher than in fish muscle and kidney. Fish liver was the organ that accumulated significantly higher quantities of nickel followed by that of kidney, gills and muscle. Both fish liver and kidney were the organs that accumulated significantly higher quantities of manganese than in gills and muscle. Among the three fish species, *Cirrhina mrigala* showed significantly lower ability to accumulate lead than *Catla catla* and *Labeo rohita.*

ii. Second year at the River Stretch from Baloki headworks to Sidhnai Barrage:

a. Iron in fish body:

Catla catla captured from Baloki headworks contained the maximum iron content of 530.50 ± 35.30 $\mu g\ g^{-1}$ in gills followed by that 404.63 ± 7.26 $\mu g\ g^{-1}$ accumulated in its liver. Both *Labeo rohita* and *Cirrhina mrigala* had the maximum iron in liver, followed by that in gills (Table 40). All the three fish species at Sidhnai barrage showed maximum iron content in the liver, followed by kidney. However, the abdominal muscles of all the three fish species collected from both the sampling stations showed significantly lowest iron.

b. Zinc in fish body:

At both Baloki headworks and Sidhnai barrage all the three fish species (except *Cirrhina mrigala* at Sidhnai barrage) accumulated significantly higher quantities of zinc in liver. The muscle showed almost least tendency for zinc accumulation (Table 41).

c. Lead in fish body:

Catla catla at Baloki headworks had the highest lead in its gills (16.00 ± 1.00 $\mu g\ g^{-1}$) while both *Labeo rohita* and *Cirrhina mrigala* accumulated maximum lead as 24.41 ± 1.13 and 17.33 ± 1.33 $\mu g\ g^{-1}$ respectively in their liver. Skin appeared to be an organ which accumulated minimum lead (Table 42). At Sidhnai barrage, both *Catla catla* and *Cirrhina mrigala* contained the maximum lead as 45.99 ± 5.74 and 22.62 ± 3.62 $\mu g\ g^{-1}$ respectively in kidney while *Labeo rohita* showed the maximum lead (15.84 ± 1.51 $\mu g\ g^{-1}$) in liver, followed by the mean contamination of 10.53 ± 0.53 $\mu g\ g^{-1}$ in muscle. The skin in both *Labeo rohita* and *Cirrhina mrigala* had the lowest contamination levels of lead (Table 42).

d. Nickel in fish body:

Table 43 shows the concentrations of nickel in six body organs of three fish species procured from Baloki headworks and Sidhnai barrage. All the three fish species contained the maximum nickel in skin, followed by that in liver. However, kidney was an organ that showed significantly lowest metal contamination levels. At Sidhnai barrage, the skin of both *Catla catla* and *Cirrhina mrigala* contained the highest nickel concentrations of 9.11 ± 0.11 and 8.60 ± 0.10 $\mu g\ g^{1}$ respectively while *Labeo rohita* accumulated significantly highest nickel in liver (8.84 ± 0.10 $\mu g\ g^{-1}$). Both *Labeo rohita* and *Cirrhina mrigala* had the least metal concentrations in muscle while the same for *Catla catla* was recorded in kidney (2.42 ± 0.07 $\mu g\ g^{-1}$).

e. Manganese in fish body:

All the three fish species at both Baloki headworks and Sidhnai barrage showed maximum accumulation of manganese in their gills while the same remained the lowest in muscle except *Cirrhina mrigala* procured from Baloki headworks which had the lowest manganese in its skin as 9.08 ± 0.28 $\mu g\ g^{-1}$ (Table 44).

Toxicity of Metals in Fish:

Analysis of variance showed statistically significant ($p < 0.01$) variations among fish organs, species and site of fish collection for the accumulation of metals (Table 45). Fish liver appeared to be an organ which had significantly higher tendency for the accumulation of iron, zinc and lead while nickel and manganese accumulations were the maximum in fish skin and gills respectively. Both iron and zinc accumulations were the minimum in fish muscle while the same for lead, nickel and manganese were in skin, kidney and muscle respectively. Among the three fish species, *Catla catla* showed significantly higher tendency for the accumulation of all the five metals in its body than the other two species of fish. However, the differences between *Catla catla* and *Labeo rohita* for the accumulation of both iron and manganese were statistically non-significant. *Cirrhina mrigala* showed significantly lower metal accumulations than rest of the two fish species. The fish at Sidhnai barrage showed significantly higher tendency than the one at Baloki headworks for the accumulation of metals in its body.

RELATIONSHIPS AMONG FISH ORGANS FOR THE UPTAKE AND ACCUMULATION OF METALS

Table 46 shows correlation coefficients among fish organs and metals toxicity in water, sediments and plankton.

i. Iron:

Iron in water showed positive and significant correlation with the contamination of fish muscle while the same for liver and kidney were negatively significant showing metal accumulation trends in fish organs. The concentration of metals in sediments were positively correlated ($p < 0.05$) with the contamination levels of fish liver and kidney. The accumulation trend of metal in plankton correlated directly with the contamination level of water while that of liver, kidney and sediments were inversely correlated at $p <$ o.05.

ii. Zinc:

Zinc in fish gills, liver and kidney had positively significant regression on the variations of metallic ions in water while the same for skin was negatively significant. Fish skin showed inverse but significant relationship with the intensity of zinc in water, sediments and plankton while the same with fish gills, liver, kidney and water were positive and significant.

iii. Lead:

Metal concentration in fish gills showed negatively significant regression on metal in water while the same for kidney was positively significant. Fish gills showed positively significant correlation while kidney and water had negatively significant correlation with lead in sediments. Plankton and sediments showed direct relationship while that of kidney and water had negatively significant relationships for the flow of lead. Sediments and water exhibited the same relationship for the metallic ion flow in aquatic ecosystem. However, the lead contamination level in fish gills correlated positively (significantly) with the metallic ions in plankton (Table 46).

iv. Nickel:

Nickel in fish scale showed inversely significant correlation with nickel in water while the correlation coefficients for all the fish organs with nickel in sediments were negative but non-significant. The flow of this metal in water and sediments showed negatively significant while that of fish scale had positively significant correlation with nickel concentration in plankton (Table 46).

v. Manganese:

Fish liver was an organ showing positively significant correlation with the contamination levels of manganese in water, sediments and plankton while the correlation of metallic ions in water was positively significant with the contamination levels of sediments and plankton (Table 46).

DISCUSSION

Chemical, toxicological and ecological approaches have been studied in assessing the impacts of heavy metals, viz. iron, zinc, lead, nickel and manganese in river Ravi aquatic environment. The data showed significance variations in metal toxicities of water, sediments and plankton among different sites of the river Ravi stretch from Shahdera to Sidhnai barrage and among different tributaries discharging effluents into the river system. These discharges adversely affected the quality of water, plankton, sediments and fish. In the river stretch from Shahdera bridge to Baloki headworks, the maximum contribution towards metallic pollution in the river was made by the Farrukhabad nulla. However, the three effluents discharging tributaries, viz. Degh nulla, Sammundri and Sukhrawa main drains at the river stretch starting from Baloki headworks to Sidhnai barrage showed variable contribution towards eco-toxicity of river for different metals.

Metals Eco-toxicity of the River Stretch from Shahdera to Baloki Headworks:

The bulk discharges of industrial wastes and domestic sewage into the river adversely affected the quality of water, plankton and sediments. However, the maximum contribution was made by the Furrukhabad nulla towards metallic 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 discharges of urban and acid mine effluents into it. Jop (1980) and Javed and Hayat (1995) reported increased heavy metal contents in the river due to discharges from municipal taming, rubber, iron and paper mills effluents.

The establishment of metal levels in the sediments is also necessary for detecting sources and extent of metal pollution in the aquatic system. The suspended particles carried by various industrial effluents and domestic sewage are ultimately deposited as the sediments containing measurable concentrations of zinc, iron, manganese, lead and nickel. The discharges of waste water from different tributaries increased the heavy metal toxicity of bottom sediments in the river. 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 the most likely sources of heavy metal contamination in tidal Lagan sediments (Manga, 1983).

The uptake and accumulations of zinc in water, sediments and plankton were dependent positively and significantly on water temperature. There is no single pattern for effects of temperature on toxicity of pollutants to aquatic organisms. 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 animal at high temperature (Hedson and Spargue, 1975). An important modifying factor in an aquatic habitat is temperature that affect ionization also. Lloyd (1992) showed a 2.5 fold increase in toxicity for an increase in temperature from 7 to 20 °C. Dissolved oxygen and pH appeared to be the variables that showed negative regression on the accumulation of metals in water, sediments and plankton. Stiff (1971) reported 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. It may be considered that unusual combination of pH, alkalinity and hardness, perhaps brought about by acid or alkaline pollution, will change to the more usual combinations, given some time and the natural aeration that takes place in surface waters. Davies *et al.* (1976) found great differences in the toxicity of lead between soft and hard water 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, plankton and sediments. It might be 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. Lloyd (1992) showed increase in lethality of copper, lead, zinc and phenols in relation to Deghree of deoxygenation.

The heavy metal concentrations in water depends mainly on the pH of the system. The pH values 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 was inversely proportion to the pH of the system and highest solubility was found at pH 7 and below. Polprasert (1982) reported that the precipitation of heavy metals is enhanced at pH 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 $\pm$ 0.20 and 7.56 $\pm$ 0.37 that 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 sediments and water respectively. Javed and Hayat (1995) observed positively significant dependence of zinc, iron and nickel concentrations in water on the electrical conductivity of water also.

The determination of heavy metal concentrations in the water samples collected from different tributaries and river reveals considerable variations. The establishment of metal levels in the sediments play an important role in determining the sources and the extent of metallic pollution at particular sampling stations. All the metals in sediments showed direct (significantly positive) relationship with the intensity of metallic ion pollution in water (Table 10). The high concentrations of all metals in sediments than in water may also be due to the precipitation of these metals with carbonates because the presence of metals in sediments would be due to the precipitation of their hydroxides, carbonates and sulfides which settle down and form the part of sediment (Forstner and Wittmann, 1981). All the metals concentrated in plankton of six tributaries and river sampling stations varied significantly (Tables 1 - 6). These accumulations in plankton were more than 66 percent dependent upon the metals in sediments. So, the heavy metals in water and sediments showed an impact on aquatic vegetation which accumulate metals in their bodies (Khan *et al.*, 1981). The capacity of algae and other plants to concentrate heavy metals in them from their aquatic environment has been observed by Harding and Whitton (1981) and Javed and Hayat (1996).

All the three fish species, captured from both Shahdera and Baloki headworks, showed non-significant differences for the pattern of zinc, iron and nickel accumulations (Table 16). Fish liver was the most contaminated organ with all the metals in three fish species. Excessive intake of metal with food and water may lead to deleterious accumulation of metal, especially in liver and kidney, causing pathological changes of the hepatocytes of the liver as well as kidney tubules and glomeruli changes (Itokawa, 1974; Colucci *et al.*, 1975).

Suspended matter and soluble metals affected the quality and quantity of the plankton in both tributaries and river. All the tributaries showed significantly lesser densities of both flora and fauna throughout the year. The streams carrying very high levels of heavy metals often have markedly reduced flora (Say and Whitton, 1981; Javed and Hayat, 1996). Meteleve *et al.* (1971) observed that the ferric hydroxide deposition on the phytolplankton reduces the rate of photosynthesis and propagation. Among phytoplankton, *Aphanocapsa, Bacillaria, Closterium, Cyclotella, Cocconeis, Cosmarium, Denticulla, Dinobryon, Euglena, Gloeocapsa, Pinnularia, Spirulina* and *Spirogyra* showed considerable tolerance against heavy metals toxicity both in tributaries and river. However, the genus, viz. *Anabaena, Arthrosira, Chlorella, Fragilaria, Frustulia, Melosira, Microcystis, Synedra, Scenedesmus, Volvox* and *Zygnema* were almost absent at highly polluted sites. Among the zooplankton, *Brachionus* and *Polyarthra* were absent in all the tributaries while occurred in the river significantly. *Keratella, Cyclops, Monnstyla* and *Filinia* were the sensitive forms and showed their existence according to the severity of pollution at different sites. Palharya and Malvia (1988) reported *Spirulina, Nostoc, Oscillatoria* and *Anabaena* as dominant and resistant forms against heavy metal toxicity in river. However, Unni (1986) reported *Keratella, Tropica, Filinia* and *Polyarthra* as tolerant forms against heavy metal toxicity. Javed and Hayat (1996) reported that the phytoplankton genera, viz. *Aphanizomenon, Bacillaria, Closterium, Cyclopedia, Cocconeis, Cosmarium, Chrococus, Denticulla, Euglena, Spirulina, Spirogyra* and *Volvox* showed considerable tolerance against heavy metals toxicity. *Keratella* and *Filinia* appeared to be the tolerant genera against heavy metals toxicity while *Cyclops* and *Philodena* were found as the sensitive forms in aquatic ecosystem.

Metals Eco-toxicity of the River Stretch from Baloki Headworks to Sidhnai Barrage:

The magnitude of heavy metal concentrations in the river water in the stretch from Baloki headworks to Sidhnai barrage was Fe > Mn > Zn > Ni > Pb. Sediments collected from the river showed the toxicity trends for different metals as Fe > Mn > Zn > Ni > Pb. Significantly higher concentrations of heavy metals in the effluent discharging tributarie's water were the resultant of the discharges from industrial and municipal waste water which enriched the heavy metal toxicity of river water significantly. He *et al.* (1998) studied the chemical, toxicological and ecological parameter in assessing the heavy metal pollution in Le An river, China. They reported water and sediment pollutions of the river were affected due to discharges from copper mines. The ecological deterioration was attributed to acid drainage instead of extremely high content of metals in the sediments. The present data indicated significant contribution of tributary's water metallic pollution towards pollution in the river.

The availability of heavy metals in an aquatic habitat is dependent on 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 an aquatic ecosystem is the hydrogen ion concentration (Polprasert, 1982). The occurrence of zinc and lead in sediments was negatively but significantly ($p < 0.01$) dependent upon the pH of water. However, the water of the whole river stretch remained alkaline during the project period. The decrease in pH of water resulted in significant increase of heavy metal toxicity in water. Weatherley *et al.* (1988) reported increased zinc toxicity of aquatic organisms under condition of low pH, low alkalinity, low dissolved oxygen, and alleviated temperature. Everall *et al.* (1989) found zinc as the most toxic in soft water at pH 4-6 and 8-9. Metzner (1977) reported increase in lead and zinc solubilities in water with the decrease in pH and the highest solubilities of these metals were recorded at pH 7. Boqomazov *et al.* (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 with the occurrence of heavy metals in water. Javed and Hayat (1999) reported increase in metal uptake by plankton with increasing water temperature. The negatively significant regression of manganese in sediments on dissolved oxygen contents of water may be due to 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 shellfish, become deprived of aquatic oxygen. Since the accumulation of all the heavy metals except manganese in plankton showed positively significant dependence on the extent of metallic ion pollution in water. So, the potential of plankton to concentrate heavy metals from aquatic environment into their bodies is evident (Harding and Whitton, 1981).

Table 32 shows the contribution of sediment toxicity on the bio-accumulation of metals in plankton in both river and tributaries. Table 33 shows the flow patterns of different metals from sediments and water towards plankton. In the river, metal ion concentrations in both bed sediments and water showed 77.77 percent contribution towards bio-magnification of iron in plankton. However, the uptake and accumulation of nickel by the plankton was positively and significantly ($p < 0.01$) dependent upon the availability of nickel in water. In tributaries, the accumulation of iron, zinc and lead in plankton was dependent upon the metals toxicity in both sediments and water. The adsorption of all the metals by the sediments showed non-significant dependence on the metal concentration in water. This shows significant impact of metal ions in water on its accumulation in plankton and adsorption by the sediments. Therefore, in an aquatic ecosystem plankton showed a great tendency to accumulate metals in their bodies from water and sediments (Khan *et al.*, 1981; Javed and Hayat, 1999). The uptake and accumulation of heavy metals by the plankton from water and sediments are obvious and that may be the reason of alleviated levels of metals in plankton collected from highly polluted river sites. However, the accumulation of different metals in all the three components i.e., water, sediments and plankton followed the order Fe > Mn > Zn > Ni > Pb. Zhou *et al.* (1998) reported the magnitude of heavy metal concentration of sediments in the rivers of Hong Kong followed the sequence: Zn > Pb > Cu > Cr > Ni > Cd. The levels of heavy metals in sediments play a key role in determining the sources and extent of metallic ion pollution in aquatic environment (Ajmal and Riaz-ud-Din, 1988; Javed, 1999). The suspended particles carried by various industrial effluents and domestic sewage are ultimately deposited at the sediments containing measurable concentrations of lead, zinc, cadmium, chromium, copper, nickel, cobalt, manganese, iron etc. (Forstner and Wittmann, 1981; Zhou *et al.*, 1998; Javed, 1999).

The presence of heavy metals in sediments would be the resultant of the precipitation of their hydroxides, carbonates and sulfides which settle down and formed the part of sediments. However, the composition of these precipitations is greatly influenced by various hydro-chemical conditions of the water body like electrical conductivity, temperature and total hardness in both river and tributary water as evident from the present results. Significantly higher concentrations of metals in the bed sediments of all the effluents discharging tributaries of the whole stretch of the river were attributed to industrial waste waters and sewage effluents being dumped into the river through these tributaries. These discharges increased the metallic ion concentrations in water which enhanced the adsorption of metals in the sediments significantly. Accumulation of lead and nickel in river sediments while zinc and nickel in the tributary sediments showed inverse (but non-significant) relationship with the metallic ions in water. Since water throughout the stretch of river Ravi was found alkaline in nature, so under alkaline pH conditions metals like iron gets hydrolyzed and forms insoluble hydroxides which settle down into the sediments of the river. The hydroxides and oxides of iron and manganese constitute significant sink of heavy metals in the aquatic ecosystem. These hydroxides and oxides readily sorbed or co-precipitated the cations and anions and even a low percentage of $Fe(OH)_3$ and MnO_3 has a controlling influence on the heavy metals distribution in an aquatic ecosystem (Jenne, 1976). The high concentrations of different metals in sediments of the river Ravi may also be attributed to the fact that metals might have been precipitated along with hydroxides and oxides of iron and manganese. Since inverse relationship was found between the water pH and all heavy metals in water, so the mobility of these metal ions in sediments have been influenced by the pH of water (Boqomazov *et al.*, 1991; Javed and Hayat, 1996).

During this research endeavor, fish has been tested as a bio-indicator of freshwater contamination by metals. Tables 34 - 38 show the accumulation trends of different metals in organs of three fish species at both Baloki headworks and Sidhnai barrage. Iron concentrations in fish iver and kidney were inversely dependent upon metal ions in water while the same for muscle was positively significant. Fish have the ability to accumulate heavy metals in their tissues by the absorption along the gill surface and gut tract wall to higher levels than the toxic concentration in their environment (Chevreuil *et al.*, 1995). Pollutants rarely distribute evenly throughout the fish body, but are accumulated by particular target organs. Fish liver appeared to be an organ which accumulated significantly higher quantities of iron, zinc and lead than the other organs. However, maximum accumulations of nickel and manganese were recorded in fish skin and gills, respectively. In general, muscle contained a smaller amount of metals than skin, scale, gills, liver and kidney. Different metals seemed to accumulate differently in fish organs. Gill as the first target for pollutants in water, absorption across the gills (Heath, 1987; Sorensen, 1991) seemed to the major pathway of lead, nickel and cadmium in fish. The relatively high contents of heavy metals found in the fish liver and kidney were due to the fact that most of the heavy metals are accumulated in the liver and kidney after ingestion (Badsha and

Goldspink, 1982) or excessive metals in the diet are not absorbed but remained in the gut and intestine. On the other hand, fish have different routes of possible excretion of heavy metals when exposed in heavy metal contaminated water bodies, these include gill, bile (via faeces), kidney and skin (Sorensen, 1991). All these factors may contribute to higher levels of heavy metals in viscera, skin and gill than in muscle.

Relationship of metals in each fraction of sediment with metal concentrations in different organs of fish showed significantly positive correlation with gills, liver and kidney while for that of skin was negatively significant. Planktonic zinc showed positively significant correlation with metal concentrations in gills, liver and kidney also. The effect of heavy metals on aquatic organisms is controlled by the concentrations and chemical forms of the metals in water and sediments. Theoretically, free metal ions are the most bio-available froms of element, and the concentration of the free metal ions varies significantly with pH and organic substances (Sorensen, 1991; Rainbow, 1995).

Lead concentrations in water showed negatively significant correlation with the accumulation of this metal in fish gills while that of kidney was positively significant. Lead in both sediments and plankton had positively significant correlation with the contamination level of gills while negatively significant with kidney. The bio-accumulation of nickel was significantly dependent on planktonic nickel. Uptake and accumulation of manganese in liver was positively and significantly dependent upon metal ions in water, sediments and plankton. The toxic effects of metals on aquatic ecosystem ranged from a complete loss of biota to subtle effects on rates of reproduction, growth, and mortality of organisms (Hodson, 1988). Metals are readily dissolved and transported in water and aquatic biota are, therefore, prone to their adverse effects. Most organisms are exposed via the direct uptake of free ions from water through respiratory surfaces, but exposure may also occur through accumulation along the food chain (plankton being the main food items of major carps) or in the case of benthos through ingestion of contaminated sediments (Dallinger *et al.*, 1987; Moriarthy and Walker, 1987).

Bio-accumulation of metals reflects the amount ingested by the organisms, the way in which the metals are distributed amongst the different tissues and the extent to which the metals are retained in each tissue type or organs. Among the three fish species, *Catla catla* accumulated significantly higher quantities of all metals, except iron and manganese than the other two species, viz. *Labeo rohita* and *Cirrhina mrigala.* The fish at Sidhnai barrage showed significantly higher tendency for the accumulation of all metals than that at the Baloki headworks. The heavy metal contents of the aquatic animals originates from two routes of intake, free ion and simple compounds dissolved in water are taken up directly through the epithelium of skin, gills and alimentary canal while others, having been accumulated in food organisms are incorporated by nutrition. Since plankton are the main food items of major carps in natural waters so, the increased levels of metals in plankton would have accumulated in fish body from plankton. The capability of algae and other plants to concentrate heavy metals in their bodies from aquatic environment has been observed by Jackson (1988) and Javed and Hayat (1996).

CONCLUSIONS

1. Present investigation reveals significant variations in the concentrations of heavy metals in the water, sediments, plankton and fish samples collected from the river which were due to the variations in the volumes of industrial and sewage wastes being added into the river through various tributaries. The effluents from various tributaries have adversely affected the quality of water, plankton, sediments and fish in the river. The current heavy metals toxicity of water at various points, viz. Farrukhabad, Bakar Mandi, Munshi Hospital, Hudiara, Taj company nullas and Degh nulla I & II, Sammundri and Sukhrawa main drains are extremely high and there has been an increasing tendency towards accumulation of metals in fish, plankton and sediments. At the same time this river still exhibits a potential for self-purification. However, if we consider rivers as the renal systems of the land spaces then, this kidney system is close to the renal failure at river Ravi.

2. The magnitude of heavy metal concentrations in the river water was Fe > Mn > Zn > Ni > Pb while sediments showed the trend: Fe > Mn > Zn > Ni > Pb.

3. In the river, metallic ion concentrations of both bed sediments and water showed 77.77 percent contribution towards bio-magnification of iron in plankton. However, the uptake and accumulation of nickel, by the plankton, were positively and significantly ($p < 0.01$) dependent upon the availability of nickel in water. The plankton in tributaries showed accumulation of iron and zinc dependent upon metallic ions in both sediments and water. The adsorption of all the metals by the sediments showed non-significant dependence on metal contaminated water. **This shows significant impact of metal ions in water on its accumulation in plankton and adsorption by the sediments. Therefore, in an aquatic ecosystem plankton showed a great tendency to accumulate metals in their bodies from water and sediments. The uptake and accumulation of heavy metals by the plankton from water and sediments are obvious and that was the reason of ellevated levels of metals in plankton collected from highly polluted river sites. However, the accumulation of different metals in all the three components i.e., water, sediments and plankton followed the order Fe > Mn > Zn > Ni > Pb.**

4. Metal concentration levels of sediments play a key role in determining the sources and extent of metallic ion pollution in an aquatic environment.

5. The concentrations of all metals in the river and effluent discharging tributaries were found significantly higher than the safe limits for sustainable conservation of freshwater fisheries and aquatic habitats as described by the EPA and PHSDWS (USA).

6. During this research endeavor, fish has been tested as a bio-indicator of freshwater contamination by metals. Iron concentrations in fish liver and kidney were inversely dependent upon metallic ions in water while the same for muscle was positively significant. Fish liver appeared to be an organ which accumulated significantly higher quantities of iron, zinc and lead than the other organs. However, maximum

accumulations of nickel and manganese were recorded in fish skin and gills respectively. In general, muscle contained a smaller amount of metals than skin, scale, gills, liver and kidney.

7. Among the three fish species, *Catla catla* showed significantly higher tendency for the accumulation of metals in its body than *Labeo rohita* and *Cirrhina mrigala*. However, the differences between *Catla catla* and *Labeo rohita* for the accumulation of both iron and manganese were statistically non-significant. *Cirrhina mrigala* showed significantly low metal accumulations. The fish at Sidhnai barrage had significantly higher tendency than the one at Baloki headworks for the accumulation of metals in its body.

8. **All the metal ions, except lead, in sediments and plankton have shown direct relationships with the intensity of water pollution. Thus, both these components of aquatic ecosystem could act as indicators of metal pollution in freshwaters.**

9. Regarding the stretch of river, from Shahdera to Baloki headworks, the phytoplankton, viz. *Aphanocapsa, Bacillaria, Closterium, Cyclotella, Cocconeis, Cosmarium, Denticulla, Dinobryon, Euglena, Gloeocapsa, Pinnularia, Spirulina* and *Spirogyra* showed considerable tolerance against heavy metals toxicity both in tributaries and river. However, the genus, viz. *Anabaena, Arthrosira, Chlorella, Fragilaria, Frustulia, Melosira, Microcystis, synedra, Scenedesmus, Volvox* and *Zygnema* were almost absent at highly polluted sites. Among the zooplankton, *Brachionus* and *Polyarthra* were absent in all the tributaries while showed their presence in the river significantly. *Keratella, Cyclops, Monnstyla* and *Filinia* were the sensitive forms and showed their existence according to the severity of pollution at different sites. The distribution of plankton in effluent discharging tributaries and at various sites of river stretch from Baloki headworks to Sidhnai barrage showed considerable variations. Myxophyceae, Bacillariopgyceae and Chlorophyceae were the important groups distributed in the river throughout the period of this study. Among phytoplankton, *Aphanocapsa, Bumilleria, Bacillaria, Cladophora, Cocconeis, Eudorina, Microcystis, Pandorina, Scendesmus, Volvox* and *Zygnema* indicated direct relationships with the intensity of pollution. However, the genus, viz. *Aphanothece, Anabaena, Arthrospira, Cyclotella, Denticulla, Dinobryon, Euglena, Navicula, Peridinium. Phacus* and *Synedra* showed considerable tolerance against heavy metal pollution. Among zooplankton, *Asplanchna, Brachionus, Canthocamptus, Cyclops, Diaptomus, Moina* and *Polyarthra* were almost absent at highly polluted sites. However, the genus, viz. *Bosmina, Filinia, Keratella* and *Monnstyla* showed considerable tolerance against metallic ion pollution. *Daphnia* appeared to ba a sensitive form against metal pollution in water.

NEED FOR ADDITIONAL RESEARCH

The discharges of industrial effluents and domestic sewage have greatly accelerated the deterioration of the aquatic environment in the river Ravi and its indigenous fish species, viz. *Catla catla, Labeo rohita* and *Cirrhina mrigala* are on the verge of extinction due to heavy loads of metals in water, plankton and sediments. Three fish species showed significant variations for the accumulation of metals in their bodies. *Catla catla* showed significantly higher tendency to accumulate metals in its body than *Labeo rohita* and *Cirrhina mrigala*. The fish at Sidhnai barrage had significantly higher metal contamination than that at Baloki headworks. Fish liver appeared to be an organ which had significantly higher tendency for the accumulation of iron, zinc and lead while nickel and manganese accumulations were the maximum in fish skin and gills respectively. These results points toward a desperate need to identify the metals tolerance limits, growth and meat quality of these fish species under varied levels of metals toxicity of water, plankton and feed in controlled conditions. Because, growth and bio-energetic parameters can act as biological indicators of metal stress in fish. Growth is a simple and straight forward index of chemical's effect on a fish because it should integrate all the effects within the fish. The out-come of this proposed project would provide basis of remedial measures to restore the river Ravi from effluent tributary to a natural riverine condition. Therefore, a new project entitled " Growth and bio-energetic studies in the fish under heavy metals toxicity" is being submitted to the PSF for funding.

PUBLICATIONS FROM THE PRESENT PROJECT WORK

The following eight (8) scientific papers have been published, based on the present project data, in various journals while three (3) research articles are almost ready for submission to international journals for publication:

01. Javed, M. and G. Mahmood, 2001. Metal toxicity of water in a stretch of river Ravi from Shahdera to Baloki head works. Pak. J. Agri. Sci., 38(1-2): In Press.

02. Javed, M. and G. Mahmood, 2000. Metals bio-accumulation in body organs and tissues of fish from the river Ravi. Pak. J. Fisheries, 1(1): 1 – 6.

03. Javed, M. and G. Mahmood, 2001. Concentration, distribution and comparison of selected heavy metals in bed sediments and fish organs from the river Ravi. Nat. Farm. Environ., 1: (4): In press.

04. Javed, M. and G. Mahmood, 2000. Studies on the metal toxicity of plankton in the river Ravi. Pak. J. Biol. Sci., 3 (12): 2165 - 2168.

05. Javed, M. 1999. Studies on metal eco-toxicity of river Ravi stretch from Shahdera to head Baloki. Pak. J. Biol. Sci., 2 (3): 1062 - 1068.

06. Javed, M. and S. Hayat, 1999. Heavy metal toxicity of river Ravi aquatic ecosystem. Pak. J. Agri. Sci.,36 (3-4): 81 - 90.

07. 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.

08. Mahmood, G., M. Javed and M. Hassan, 2000. Assessment of the river Ravi for the physico - chemistry and heavy metals toxicity of water. Pak. J. Biol. Sci., 3(11): 1962 - 1964.

M. Phil / Ph. D. DEGREES:

The following six (6) post-graduate students completed their research work from the present PSF project:

S.No.	Name of Research Personnel	Registration No.	Degree obtained/to be obtained
01.	Muhammad Ubaidullah	(85-ag-520)	Ph. D. research work completed.
02.	Ghazanfar Mahmood, (Res. Associate)	(93 -ag-1425)	M. Phil. Degree completed.
03.	Sajid Abdullah	(97 -ag-927)	M. Sc. Degree completed.
04.	Zawar Hussain	(97 - ag - 1891)	M. Sc. Degree completed.
05.	Aima Iram	(97 - ag - 1765)	M. Sc. Degree completed.
06.	Ambrina Batool	(97 - ag - 1777)	M. Sc. Degree completed.

LIST OF SCIENTISTS:

S.NO.	NAME OF SCIENTIST	DESIGNATION
01.	Dr. Muhammad Javed	Principal Investigator, Associate Professor,/ Officer In-Charge, FRF
02.	Ghazanfar Mahmood,	Research Associate & M. Phil. Scholar
03.	Muhammad Ubaidullah	Ph. D. Scholar.
04.	Sajid Abdullah	M. Sc. Scholar
05.	Zawar Hussain	M. Sc. Scholar
06.	Aima Iram	M. Sc. Scholar
07.	Ambrina Batool	M. Sc. Scholar

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TABLES

TABLE: 1. Mean zinc concentrations in different effluent discharging tributaries and river.

EFFLUENT TRIBUTARY SAMPLING STATIONS			RIVER SITE SAMPLING STATIONS		
WATER (mg l^{-1})					
T1	Farrukhabad Nulla	3.92 ± 2.04 a	**R1**	Shahdera bridge	0.52 ± 0.16 c
T2	Munshi Hosp.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 Head works	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			
SEDIMENTS ($\mu g\ g^{-1}$ ± SD)					
T1	Farrukhabad Nulla	406.50 ± 34.67 a	**R1**	Shahdera bridge	79.63 ± 8.99 d
T2	Munshi Hosp.Nulla	184.10 ± 17.35 e	**R2**	Baradarri	94.73 ± 7.53 c
T3	Taj Company Nulla	229.50 ± 22.48 d	**R3**	Sharqpur	133.60 ± 28.95 a
T4	Bakar Mandi Nulla	346.80 ± 19.40 b	**R4**	Thatta Polian wala	99.85 ± 20.11 b
T5	Hudiara Nulla	242.70 ± 16.23 c	**R5**	I/b Q.B.canal and Baloki Head works	75.69 ± 24.75 e
T6	Degh fall	91.19 ± 14.95 f	**R6**	Head Baloki	90.00 ± 7.38 c
MEANS:	TRIBUTARY WATER :	250.13 ± 113.48 a			
	RIVER WATER :	95.58 ± 20.71 b			
PLANKTON ($\mu g\ g^{-1}$ ± SD)					
T1	Farrukhabad Nulla	199.10 ± 22.54 b	**R1**	Shahdera bridge	82.96 ± 13.28 c
T2	Munshi Hosp.Nulla	142.20 ± 4.82 d	**R2**	Baradarri	85.75 ± 10.10 c
T3	Taj Company Nulla	199.90 ± 6.81 b	**R3**	Sharqpur	141.80 ± 11.25 a
T4	Bakar Mandi Nulla	191.60 ± 14.25 c	**R4**	Thatta Polian wala	79.52 ± 4.81 d
T5	Hudiara Nulla	206.00 ± 4.85 a	**R5**	I/b Q.B.canal and Baloki Head works	62.67 ± 3.77 e
T6	Degh fall	129.80 ± 9.64 e	**R6**	Head Baloki	102.67 ± 5.20 b
MEANS:	TRIBUTARY WATER :	178.10 ± 33.16 a			
	RIVER WATER :	92.56 ± 27.31 b			

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

TABLE: 2. Mean iron concentrations in different effluent discharging tributaries and river.

EFFLUENT TRIBUTARY SAMPLING STATIONS			RIVER SITE SAMPLING STATIONS		
WATER (mg l^{-1})					
T1	Farrukhabad Nulla	11.89 ± 6.04 a	**R1**	Shahdera bridge	6.84 ± 3.70 d
T2	Munshi Hosp.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 Head works	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			
SEDIMENTS (**$\mu g\ g^{-1}$ ± SD**)					
T1	Farrukhabad Nulla	24260.15 ± 871.50 a	**R1**	Shahdera bridge	14580.10 ± 240.62 c
T2	Munshi Hosp.Nulla	13820.92 ± 200.01 b	**R2**	Baradarri	18200.25 ± 205.83 a
T3	Taj Company Nulla	10000.21 ± 164.68 d	**R3**	Sharqpur	15140.81 ± 501.68 c
T4	Bakar Mandi Nulla	11550.44 ± 210.05 c	**R4**	Thatta Polian wala	14760.39 ± 270.33 c
T5	Hudiara Nulla	12270.65 ± 270.33 c	**R5**	I/b Q.B.canal and Baloki Head works	13490.48 ± 190.15 d
T6	Degh fall	10590.31 ± 137.90 d	**R6**	Head Baloki	17300.23 ± 140.33 b
MEANS:	TRIBUTARY WATER :	13748.78 ± 5320.51 b			
	RIVER WATER :	15578.71 ± 1791.95 a			
PLANKTON (**$\mu g\ g^{-1}$ ± SD**)					
T1	Farrukhabad Nulla	7351.00 ± 194.65 a	**R1**	Shahdera bridge	1874.66 ± 48.62 f
T2	Munshi Hosp.Nulla	4592.50 ± 50.21 b	**R2**	Baradarri	4893.28 ± 160.20 d
T3	Taj Company Nulla	3505.38 ± 30.94 c	**R3**	Sharqpur	5277.20 ± 94.37 c
T4	Bakar Mandi Nulla	3083.42 ± 28.52 d	**R4**	Thatta Polian wala	5820.54 ± 82.30 a
T5	Hudiara Nulla	2995.54 ± 90.11 e	**R5**	I/b Q.B.canal and Baloki Head works	5439.38 ± 43.01 b
T6	Degh fall	2300.55 ± 35.92 f	**R6**	Head Baloki	4712.09 ± 54.38 e
MEANS:	TRIBUTARY WATER :	3971.40 ± 1819.73 a			
	RIVER WATER :	4669.52 ± 1424.77 b			

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

TABLE: 3. **Mean Manganese concentrations in different effluent discharging tributaries and river.**

EFFLUENT TRIBUTARY SAMPLING STATIONS		RIVER SITE SAMPLING STATIONS		
WATER (mg l^{-1})				
T1 Farrukhabad Nulla	3.07 ± 0.66 a	**R1**	Shahdera bridge	0.72 ± 0.37 d
T2 Munshi Hosp.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 Head works	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			
SEDIMENTS ($\mu g\ g^{-1}$ ± SD)				
T1 Farrukhabad Nulla	2895.23 ± 420.55 c	**R1**	Shahdera bridge	1505.28 ± 170.32 e
T2 Munshi Hosp.Nulla	3536.40 ± 300.37 a	**R2**	Baradarri	1710.54 ± 243.82 d
T3 Taj Company Nulla	3405.39 ± 294.58 b	**R3**	Sharqpur	2072.28 ± 192.32 bc
T4 Bakar Mandi Nulla	2472.55 ± 243.88 d	**R4**	Thatta Polian wala	2112.20 ± 132.98 b
T5 Hudiara Nulla	3572.84 ± 210.30 a	**R5**	I/b Q.B.canal and Baloki Head works	2188.29 ± 79.63 a
T6 Degh fall	2471.92 ± 190.36 d	**R6**	Head Baloki	2065.01 ± 63.00 c
MEANS: TRIBUTARY WATER :	3059.05 ± 515.23 a			
RIVER WATER :	1942.27 ± 270.56 b			
PLANKTON ($\mu g\ g^{-1}$ ± SD)				
T1 Farrukhabad Nulla	681.20 ± 30.22 a	**R1**	Shahdera bridge	220.50 ± 10.35 c
T2 Munshi Hosp.Nulla	746.40 ± 40.58 a	**R2**	Baradarri	240.80 ± 12.55 c
T3 Taj Company Nulla	703.20 ± 34.93 a	**R3**	Sharqpur	474.80 ± 32.78 a
T4 Bakar Mandi Nulla	439.30 ± 32.11 b	**R4**	Thatta Polian wala	482.60 ± 21.21 a
T5 Hudiara Nulla	741.90 ± 40.53 a	**R5**	I/b Q.B.canal and Baloki Head works	391.90 ± 24.54 b
T6 Degh fall	281.50 ± 13.94 c	**R6**	Head Baloki	257.70 ± 14.99 c
MEANS: TRIBUTARY WATER :	598.92 ± 192.91 a			
RIVER WATER :	344.72 ± 119.97 b			

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

TABLE: 4. Mean lead concentrations in different effluent discharging tributaries and river.

EFFLUENT TRIBUTARY SAMPLING STATIONS			RIVER SITE SAMPLING STATIONS		
WATER (mg l^{-1})					
T1	Farrukhabad Nulla	0.83 ± 0.29 a	**R1**	Shahdera bridge	0.25 ± 0.05 d
T2	Munshi Hosp.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 Head works	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			
SEDIMENTS ($\mu g\ g^{-1} \pm SD$)					
T1	Farrukhabad Nulla	378.80 ± 34.87 a	**R1**	Shahdera bridge	133.20 ± 20.31 e
T2	Munshi Hosp.Nulla	150.70 ± 21.65 f	**R2**	Baradarri	131.00 ± 16.88 e
T3	Taj Company Nulla	159.50 ± 24.87 e	**R3**	Sharqpur	220.10 ± 21.39 b
T4	Bakar Mandi Nulla	297.80 ± 31.55 b	**R4**	Thatta Polian wala	225.00 ± 11.06 a
T5	Hudiara Nulla	287.20 ± 19.64 c	**R5**	I/b Q.B.canal and Baloki Head works	203.70 ± 10.85 c
T6	Degh fall	209.80 ± 16.16 d	**R6**	Head Baloki	164.30 ± 7.35 d
MEANS:	TRIBUTARY WATER :	247.30 ± 89.31 a			
	RIVER WATER :	179.55 ± 42.50 b			
PLANKTON ($\mu g\ g^{-1} \pm SD$)					
T1	Farrukhabad Nulla	11.18 ± 4.05 a	**R1**	Shahdera bridge	5.74 ± 1.37 b
T2	Munshi Hosp.Nulla	6.83 ± 1.04 c	**R2**	Baradarri	4.21 ± 2.01 e
T3	Taj Company Nulla	4.05 ± 1.21 f	**R3**	Sharqpur	9.55 ± 3.94 a
T4	Bakar Mandi Nulla	5.33 ± 1.73 e	**R4**	Thatta Polian wala	4.71 ± 0.72 d
T5	Hudiara Nulla	7.37 ± 2.54 b	**R5**	I/b Q.B.canal and Baloki Head works	5.03 ± 0.58 c
T6	Degh fall	5.91 ± 1.14 d	**R6**	Head Baloki	4.01 ± 0.42 f
MEANS:	TRIBUTARY WATER :	6.78 ± 2.45 a			
	RIVER WATER :	5.56 ± 2.04 b			

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

TABLE: 5. Mean nickel concentrations in different effluent discharging tributaries and river.

EFFLUENT TRIBUTARY SAMPLING STATIONS		RIVER SITE SAMPLING STATIONS	
WATER (mg l^{-1})			
T1 Farrukhabad Nulla	2.43 ± 0.27 a	**R1** Shahdera bridge	0.46 ± 0.15 e
T2 Munshi Hosp.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 Head works	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		
SEDIMENTS (µg g^{-1} ± SD)			
T1 Farrukhabad Nulla	863.04 ± 4.37 a	**R1** Shahdera bridge	259.00 ± 11.25 e
T2 Munshi Hosp.Nulla	469.60 ± 23.21 f	**R2** Baradarri	431.50 ± 8.02 c
T3 Taj Company Nulla	521.40 ± 28.14 d	**R3** Sharqpur	473.90 ± 18.22 b
T4 Bakar Mandi Nulla	604.50 ± 11.25 c	**R4** Thatta Polian wala	509.00 ± 14.95 a
T5 Hudiara Nulla	731.40 ± 16.77 b	**R5** I/b Q.B.canal and Baloki Head works	431.20 ± 7.34 c
T6 Degh fall	489.00 ± 21.59 e	**R6** Head Baloki	381.20 ± 6.22 d
MEANS: TRIBUTARY WATER :	613.22 ± 155.64 a		
RIVER WATER :	414.30 ± 87.54 b		
PLANKTON (µg g^{-1} ± SD)			
T1 Farrukhabad Nulla	14.97 ± 1.94 b	**R1** Shahdera bridge	5.29 ± 0.94 e
T2 Munshi Hosp.Nulla	8.31 ± 2.34 e	**R2** Baradarri	6.10 ± 0.35 d
T3 Taj Company Nulla	10.26 ± 4.21 d	**R3** Sharqpur	9.24 ± 3.01 a
T4 Bakar Mandi Nulla	10.97 ± 3.61 c	**R4** Thatta Polian wala	8.47 ± 2.11 b
T5 Hudiara Nulla	15.95 ± 6.11 a	**R5** I/b Q.B.canal and Baloki Head works	6.86 ± 0.87 c
T6 Degh fall	8.06 ± 1.38 e	**R6** Head Baloki	6.79 ± 0.32 c
MEANS: TRIBUTARY WATER :	11.42 ± 3.33 a		
RIVER WATER :	7.12 ± 1.47 b		

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

TABLE: 6. **Mean values for physico-chemical parameters (± SD) in different effluent discharging tributaries and river water.**

EFFLUENT TRIBUTARY SAMPLING STATIONS			RIVER SITE SAMPLING STATIONS	
TEMPERATURE (°C)				
T1 Farrukhabad Nulla	28.36 ± 5.52 a	**R1**	Shahdera bridge	26.16 ± 5.52 ab
T2 Munshi Hosp.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**	I/b Q.B.canal and Baloki Head works	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 (μs)				
T1 Farrukhabad Nulla	1038.30 ± 159.56 d	**R1**	Shahdera bridge	299.40 ± 61.91 d
T2 Munshi Hosp.Nulla	1338.28 ± 87.87 b	**R2**	Baradarri	302.90 ± 54.54 d
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 ± 188.64 a
T5 Hudiara Nulla	1983.04 ± 262.20 a	**R5**	I/b Q.B.canal and Baloki Head works	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 ± 128.73 b			
DISSOLVED OXYGEN (mg l^{-1})				
T1 Farrukhabad Nulla	0.97 ± 0.43 d	**R1**	Shahdera bridge	7.27 ± 0.45 b
T2 Munshi Hosp.Nulla	2.10 ± 0.78 c	**R2**	Baradarri	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**	I/b Q.B.canal and Baloki Head works	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			

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

TABLE: 7. **Mean water pH, total hardness and manganese values in different effluent discharging tributaries and river.**

EFFLUENT TRIBUTARY SAMPLING STATIONS		RIVER SITE SAMPLING STATIONS	
<u>**pH**</u>			
T1 Farrukhabad Nulla	7.45 ± 0.25 b	**R1** Shahdera bridge	8.12 ± 0.09 bc
T2 Munshi Hosp.Nulla	7.53 ± 0.30 b	**R2** Baradarri	8.00 ± 0.16 c
T3 Taj Company Nulla	7.31 ± 0.27 c	**R3** Sharqpur	8.09 ± 0.22 bc
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** I/b Q.B.canal and Baloki Head works	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		
<u>**TOTAL HARDNESS**</u> (mg l^{-1})			
T1 Farrukhabad Nulla	371.50 ± 37.11 c	**R1** Shahdera bridge	178.40 ± 25.91 d
T2 Munshi Hosp.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** I/b Q.B.canal and Baloki Head works	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		
<u>**MAGNESIUM**</u> (mg l^{-1})			
T1 Farrukhabad Nulla	17.65 ± 4.93 e	**R1** Shahdera bridge	10.48 ± 1.36 b
T2 Munshi Hosp.Nulla	18.91 ± 2.50 d	**R2** Baradarri	12.90 ± 2.55 a
T3 Taj Company Nulla	23.94 ± 2.53 c	**R3** Sharqpur	9.22 ± 1.15 d
T4 Bakar Mandi Nulla	31.24 ± 4.30 b	**R4** Thatta Polian wala	9.47 ± 1.21 c
T5 Hudiara Nulla	36.48 ± 6.01 a	**R5** I/b Q.B.canal and Baloki Head works	9.51 ± 1.21 c
T6 Degh fall	11.72 ± 1.87 f	**R6** Head Baloki	9.27 ± 0.81 c
MEANS: TRIBUTARY WATER :	23.32 ± 9.19 a		
RIVER WATER :	10.14 ± 1.43 b		

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

Table: 8 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.)
01. Zinc	0.01 mg/l	0.01 mg/l	0.01 mg/l	5.00 mg/ l
02. Iron	0.36 mg/l	NA	0.03 mg/l	2.00 mg/ l
03. Manganese	0.50 mg/l	NA	0.05 mg/l	1.50 mg/ l
04. Cadmium	1.20 mg/l	12.00 mg/l	0.01 mg/l	0.10 mg/ l
05. Lead	0.01 mg/l	0.01 mg/l	0.05 mg/l	0.50 mg/ l
06. Nickel	0.01 mg/l	0.01 mg/l	0.001 mg/l	1.00 mg/ l
07. Mercury	0.03 mg/l	0.05 mg/l	0.002 mg/l	0.01 mg/ l

* Haslam, S.M., 1991 ; ** Corbitt, R.A., 1990 ; NA = Not available: PHSDWS = Public Health Service Drinking Water Standards (USA)

TABLE: 9 Relationships among physico-chemical variables, uptake and accumulation of different metals in water, sediments and plankton.

	REGRESSION EQUATION	r/MR	R^2
ZINC			
Zinc in water =	-17.77 + 0.71 (Temp.)	0.7748	0.6002
	**		
SE =	0.12		
Zinc in sed. =	- 1518.14 + 0.09 (E.C.) - 28.29 (DO) + 70.43 (Temp.)	0.9313	0.8673
	* ** **		
SE =	0.04 8.98 13.45		
Zinc in Plk. =	- 278.87 - 10.62 (DO) + 17.34 (Temp.)	0.8422	0.7093
	** *		
SE =	3.79 9.19		
IRON			
Iron in water =	1.94 + 0.08(Hard.) - 0.02 (E.C.) - 0.51 (DO)	0.9281	0.8614
	** ** **		
SE =	0.008 0.001 0.18		
Iron in sed. =	No variable meet criteria		
Iron in plk. =	No variable meet criteria		
MANGANESE			
Mn in water =	1.80 + 0.01(Hard.) - 0.003(E.C.) - 0.34 (DO)	0.9570	0.9158
	** ** **		
SE =	0.001 0.000 0.038		
Mn in sed. =	16399.61 + 1.45(E.C.) - 794.03 (pH) - 326.70((Temp.)	0.9428	0.8889
	** ** **		
SE =	0.15 205.95 98.43		
Mn in plk. =	957.98 + 1.59(Hard.) - 115.69(pH)	0.8838	0.7812
	** **		
SE =	0.01 8.35		
LEAD			
Lead in water =	- 0.99 - 0.05(DO) + 0.06 (Temp.)	0.8747	0.7651
	** *		
SE =	0.01 0.02		
Lead in sed. =	289.29 - 17.79(DO)	- 0.6221	0.3870
	**		
SE =	4.77		
Lead in plk. =	7.76 - 0.37(DO)	- 0.4386	0.1924
	*		
SE =	0.16		
NICKEL			
Nickel in water =	- 8.06 + 0.33(Temp.)	- 0.6817	0.4648
	**		
SE =	0.07		
Nickel in sed. =	721.56 - 48.75(DO)	- 0.8092	0.6547
	**		
SE =	7.55		
Nickel in plk. =	1.41 +0.03(Hard.)	0.8648	0.7478
	**		
SE =	0.003		

* = Significant at $p< 0.05$; ** = Significant at $p< 0.01$
Sed= sediment; Plk.= plankton; Temp. = temperature; E.C. = electrical conductivity; DO = dissolved oxygen; Hard = total hardness

TABLE: 10 Uptake and accumulation of heavy metals in river Ravi aquatic ecosystem.

	REGRESSION EQUATION	r/MR	R^2
ZINC			
Plank. Zinc	= 74.87 + 0.38 (S. Zinc) ** (0.06)	0.7952	0.6323
Plank. Zinc	= 64.28 + 0.72 (S. Zinc) - 40.22 (W. Zinc) ** ; * (0.17) ; (18.94)	0.8351	0.6973
IRON			
Plank. Iron	= - 72.28 + 0.30(S. Iron) ** (0.05)	0.7326	0.5366
MANGANESE			
Plank. Manganese	= - 178.75 + 0.26(S. Mn) ** (0.03)	0.8934	0.7982
LEAD			
Plank. Lead	= - 1.95 + 0.02(S. Lead) ** (0.004)	0.6621	0.4384
NICKEL			
Plank. Nickel	= - 0.86 + 0.02(S.Nickel) ** (0.001)	0.9408	0.8851
ZINC			
Sed. Zinc	= 47.22 + 105.06(W.Zinc)	0.9420	0.8874
Sed. Zinc	= - 15.63 + 82.56(W. Zinc) + 0.64(P. Zinc) ** ; ** (8.03) ; (0.15)	0.9691	0.9391
IRON			
Sed. Iron	= 5013.72 + 1544.51(W. Iron) ** (137.91)	0.9224	0.8508
MANGANESE			
Sed. Manganese	= 1052.89 + 3.07(P. Mn) ** (0.3288)	0.8934	0.7982
LEAD			
Sed. Lead	= 77.83 + 257.47(W. Lead) ** (50.33)	0.7371	0.5433
Sed. Lead	= 44.81 + 185.46(W. Lead) + 11.51(P. Lead) ** ; * (58.87) ; (5.65)	0.7865	0.6186
NICKEL			
Sed.Nickel	= 97.58 + 44.88 (P. Nickel) ** (3.45)	0.9408	0.8851
Sed. Nickel	= 124.24 + 32.59 (P. Nickel) + 102.51(W. Nickel) ** ; ** (3.97) ; (24.97)	0.9677	0.9365

Values within brackets are the standard errors.
Plank. = planktonic; S. = sedimental; W = water

Head Baloki	<u>Catla</u> <u>catla</u>	4	8
	<u>Labeo</u> <u>rohita</u>	15	9
	<u>Cirrhina</u> <u>mrigala</u>	9	6

Head Baloki	Catla catla	4	8
	Labeo rohita	15	9
	Cirrhina mrigala	9	6

TABLE: 13. **Concentration of Manganese (μg g^{-1}) in fish body.**

SAMPLING STATION	FISH SPECIES	S. SIZE (No.)	AVERAGE WEIGHT (g)	METAL CONCENTRATION IN FISH BODY (μg g^{-1})			
				Muscle	Gills	Liver	Kidney
Shahdera	Catla catla	2	480.25 ± 62.02	10.62 ± 2.01	12.28 ± 1.11	20.64 ± 4.35	14.22 ± 2.01
	Labeo rohita	14	810.91 ± 111.39	6.38 ± 1.95	10.35 ± 1.34	18.30 ± 5.32	13.05 ± 2.50
	Cirrhina mrigala	7	624.05 ± 94.66	6.40 ± 2.20	10.66 ± 2.01	18.95 ± 3.05	14.00 ± 1.68
Head Baloki	Catla catla	4	885.62 ± 90.25	9.05 ± 2.55	10.95 ± 1.50	22.28 ± 4.57	15.08 ± 1.50
	Labeo rohita	15	990.60 ± 138.65	7.82 ± 1.82	8.68 ± 1.38	19.66 ± 3.85	16.25 ± 1.65
	Cirrhina mrigala	9	673.20 ± 120.91	7.58 ± 2.01	10.25 ± 1.67	20.28 ± 3.25	14.68 ± 1.80

Head Baloki	*Catla catla*	4	8
	Labeo rohita	15	9
	Cirrhina mrigala	9	6

TABLE: 15. Concentration of nickel ($\mu g\ g^{-1}$) in fish body.

SAMPLING STATION	FISH SPECIES	S. SIZE (No.)	AVERAGE WEIGHT (g)	METAL CONCENTRATION IN FISH BODY ($\mu g\ g^{-1}$)			
				Muscle	Gills	Liver	Kidney
Shahdera Bridge	Catla catla	2	480.25 ± 62.02	0.84 ± 0.20	3.05 ± 0.33	8.90 ± 1.05	3.62 ± 0.02
	Labeo rohita	14	810.91 ± 111.39	1.35 ± 0.10	2.88 ± 0.35	8.01 ± 0.30	4.35 ± 0.66
	Cirrhina mrigala	7	624.05 ± 94.66	1.84 ± 0.35	2.90 ± 0.28	7.34 ± 0.42	4.00 ± 0.35
Head Baloki	Catla catla	4	885.62 ± 90.25	1.00 ± 0.05	3.40 ± 1.05	8.25 ± 0.33	3.43 ± 0.40
	Labeo rohita	15	990.60 ± 138.65	1.42 ± 0.09	2.90 ± 0.80	8.30 ± 0.95	3.94 ± 0.38
	Cirrhina mrigala	9	673.20 ± 120.91	1.59 ± 0.12	3.15 ± 0.35	7.49 ± 1.31	3.84 ± 0.25

TABLE: 16 Comparison of fish organs, species and sites of fish collection for the accumulation of metals.

VARIABLE	**MEAN SQUARES**				
(S.O.V.)	ZINC	IRON	MANGANESE	LEAD	NICKEL
Fish organs	(P<0.01) 1476.15	(P<0.01) 95980.66	(P<0.01) 165.45	(P<0.01) 18.77	(P<0.01) 48.74
Fish species	182.99	313.01	(P<0.01) 7.73	(P<0.01) 18.70	0.03
Sites of fish collection	19.33	154.28	1.88	0.22	0.01
Error	140.24	613.29	1.13	2.09	0.19

COMPARISON OF MEANS ($\mu g\ g^{-1}$)

VARIABLE	**ZINC**	**IRON**	**MANGANESE**	**LEAD**	**NICKEL**
FISH ORGANS:					
Fish Muscle	72.50 b	72.86 c	7.97 d	6.87 b	1.34 d
Fish Gills	70.88 b	271.40 b	10.53 c	9.89 a	3.05 c
Fish Liver	104.80 a	377.80 a	20.02 a	10.66 a	8.05 a
Fish Kidney	79.98 b	250.90 b	14.55 b	7.79 b	3.86 b
FISH SPECIES:					
Catla catla	84.80 a	249.67 a	14.39 a	10.26 a	4.06 a
Labeo rohita	76.52 a	242.87 a	12.56 b	8.94 a	4.14 a
Cirrhina mrigala	84.80 a	237.18 a	12.85 b	7.21 b	4.02 a

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

TABLE: 17 Relationships among fish body, water, plankton and sediments for the flow of heavy metals in river aquatic ecosystem.

METAL IN:	WATER	PLANKTON	SEDIMENT
ZINC IN:			
Plankton	0.8826		
Sediment	0.8692	0.6723	
Fish body	0.1869	0.0736	0.4824
IRON IN:			
Plankton	0.6271		
Sediment	0.6514	0.9726	
Fish body	- 0.1262	0.2403	- 0.0802
MANGANESE IN:			
Plankton	- 0.0756		
Sediment	- 0.2604	0.9629	
Fish body	- 0.1734	- 0.0625	- 0.0933
LEAD IN:			
Plankton	- 0.4449		
Sediment	- 0.4519	- 0.4502	
Fish body	- 0.2241	0.5780	- 0.3739
NICKEL IN:			
Plankton	0.4718		
Sediment	0.6282	0.6379	
Fish body	- 0.4602	- 0.4602	- 0.6515

Critical value (1-tail, 0.05) = + or - 0.6265

Table: 18. **Iron toxicity in the river and effluent discharging tributaries.**

River stations				Tributaries			
Water (mg L^{-1} ± SD)							
R1	Baloki headworks	8.71 ± 3.72	a	**T1**	Degh Nulla	9.85 ± 2.25	a
R2	Syedwala	6.89 ± 2.29	d	**T2**	Sammundri M.D.	7.48 ± 0.78	c
R3	Mari Pattan	7.06 ± 1.26	c	**T3**	Sukhrawa M.D.	8.05 ± 2.04	b
R4	K. C. bridge	6.00 ± 1.77	e				
R5	Sidhnai barrage	7.77 ± 2.54	b				
SE:		0.1012				0.0575	
Means For:	First year	4.97 ± 0.54	b			6.78 ± 0.65	b
	Second year	9.60 ± 1.66	a			10.14 ± 1.57	a
Sediments (μg g^{-1} ± SD)							
R1	Baloki headworks	14638.00 ± 2431.92	c	**T1**	Degh Nulla	20101.67 ± 2465.30	b
R2	Syedwala	14632.39 ± 2425.10	c	**T2**	Sammundri M.D.	15218.77 ± 1961.60	c
R3	Mari Pattan	14640.86 ± 5297.61	c	**T3**	Sukhrawa M.D.	23754.10 ± 7672.15	a
R4	K. C. bridge	16921.95 ± 4177.06	a				
R5	Sidhnai barrage	15112.15 ± 3206.95	b				
SE :		87.2600				174.3000	
Means For :	First year	11681.64 ± 1201.28	b			15659.74 ± 1816.82	b
	Second year	18696.50 ± 1599.66	a			23723.29 ± 5873.60	a
Plankton (μg g^{-1} ± SD)							
R1	Baloki headworks	7993.95 ± 4901.49	a	**T1**	Degh Nulla	7199.94 ± 3261.68	b
R2	Syedwala	3078.63 ± 2076.63	e	**T2**	Sammundri M.D.	10488.36 ± 6370.69	a
R3	Mari Pattan	4253.04 ± 2073.47	d	**T3**	Sukhrawa M.D.	3744.10 ± 833.38	c
R4	K. C. bridge	4999.15 ± 2230.61	c				
R5	Sidhnai barrage	6520.90 ± 2627.54	b				
SE :		15.3400				41.8300	
Means For :	First year	2587.21 ± 966.82	b			3655.61 ± 531.80	b
	Second year	8151.06 ± 2707.64	a			10632.66 ± 5015.47	a

Means with similar letters in a single column are statistically similar at $p < 0.05$
M.D. = main drain

Table: 19. Zinc toxicity in the river and effluent discharging tributaries.

River stations				Tributaries			
Water (mg L^{-1} ± SD)							
R1	Baloki headworks	2.12 ± 0.10	d	**T1**	Degh Nulla	3.27 ± 0.47	a
R2	Syedwala	2.27 ± 0.18	c	**T2**	Sammundri M.D.	3.01 ± 0.48	b
R3	Mari Pattan	2.58 ± 0.12	a	**T3**	Sukhrawa M.D.	1.84 ± 0.03	c
R4	K. C. bridge	2.25 ± 0.29	c				
R5	Sidhnai barrage	2.35 ± 0.54	b				
SE:		0.0506				0.0575	
Means For:	First year	2.10 ± 0.22	b			2.40 ± 0.39	b
	Second year	2.46 ± 0.31	a			3.01 ± 0.85	a
Sediments (μg g^{-1} ± SD)							
R1	Baloki headworks	180.16 ± 12.59	e	**T1**	Degh Nulla	437.89 ± 19.11	b
R2	Syedwala	431.83 ± 35.70	a	**T2**	Sammundri M.D.	550.04 ± 370.43	a
R3	Mari Pattan	293.05 ± 42.04	c	**T3**	Sukhrawa M.D.	290.22 ± 4.57	c
R4	K. C. bridge	247.23 ± 139.99	d				
R5	Sidhnai barrage	348.76 ± 151.91	b				
SE :		3.2070				10.9600	
Means For :	First year	296.57 ± 96.14	b			544.80 ± 270.49	a
	Second year	303.85 ± 154.47	a			307.30 ± 114.07	b
Plankton (μg g^{-1} ± SD)							
R1	Baloki headworks	148.98 ± 88.70	e	**T1**	Degh Nulla	193.99 ± 122.87	c
R2	Syedwala	169.13 ± 120.76	c	**T2**	Sammundri M.D.	341.98 ± 268.97	a
R3	Mari Pattan	170.59 ± 106.23	b	**T3**	Sukhrawa M.D.	245.05 ± 184.08	b
R4	K. C. bridge	184.45 ± 105.07	a				
R5	Sidhnai barrage	157.10 ± 108.19	d				
SE :		1.0780				2.3730	
Means For :	First year	60.26 ± 11.43	b			68.37 ± 5.29	b
	Second year	271.84 ± 19.37	a			452.31 ± 121.18	a

Means with similar letters in a single column are statistically similar at $p < 0.05$. ; M.D. = main drain

Table: 20. Lead toxicity in the river and effluent discharging tributaries.

River stations				Tributaries			
Water (mg L^{-1} ± SD)							
R1	Baloki headworks	0.53 ± 0.13	e	**T1**	Degh Nulla	1.25 ± 0.29	a
R2	Syedwala	0.77 ± 0.24	b	**T2**	Sammundri M.D.	1.22 ± 0.30	b
R3	Mari Pattan	0.58 ± 0.17	d	**T3**	Sukhrawa M.D.	1.01 ± 0.50	c
R4	K. C. bridge	1.88 ± 0.22	a				
R5	Sidhnai barrage	0.68 ± 0.07	c				
SE:		0.0051				0.0182	
Means For:	First year	0.94 ± 0.39	a			0.80 ± 0.20	b
	Second year	0.84 ± 0.64	b			1.52 ± 0.02	a
Sediments (µg g^{-1} ± SD)							
R1	Baloki headworks	133.90 ± 2.11	a	**T1**	Degh Nulla	87.67 ± 8.94	c
R2	Syedwala	120.58 ± 12.71	b	**T2**	Sammundri M.D.	115.69 ± 6.22	b
R3	Mari Pattan	83.24 ± 4.89	c	**T3**	Sukhrawa M.D.	136.82 ± 14.07	a
R4	K. C. bridge	49.44 ± 40.12	e				
R5	Sidhnai barrage	68.68 ± 27.86	d				
SE :		0.7705				1.0540	
Means For :	First year	95.60 ± 35.73	a			107.80 ± 20.57	b
	Second year	86.75 ± 41.41	b			118.99 ± 23.16	a
Plankton (µg g^{-1} ± SD)							
R1	Baloki headworks	20.91 ± 15.35	b	**T1**	Degh Nulla	24.06 ± 17.20	a
R2	Syedwala	23.92 ± 19.62	a	**T2**	Sammundri M.D.	15.49 ± 8.63	c
R3	Mari Pattan	19.33 ± 15.27	c	**T3**	Sukhrawa M.D.	18.63 ± 14.68	b
R4	K. C. bridge	17.74 ± 13.95	d				
R5	Sidhnai barrage	17.18 ± 12.67	e				
SE :		0.1959				0.1521	
Means For :	First year	4.44 ± 0.61	b			5.89 ± 1.37	b
	Second year	31.19 ± 4.73	a			32.90 ± 7.01	a

Means with similar letters in a single column are statistically similar at $p < 0.05$
M.D. = main drain

Table: 21. Nickel toxicity in the river and effluent discharging tributaries.

River stations				Tributaries			
Water (mg L^{-1} ± SD)							
R1	Baloki headworks	1.74 ± 0.44	b	**T1**	Degh Nulla	1.91 ± 0.85	a
R2	Syedwala	1.59 ± 0.63	d	**T2**	Sammundri M.D.	1.88 ± 0.63	b
R3	Mari Pattan	1.68 ± 0.63	c	**T3**	Sukhrawa M.D.	1.81 ± 0.45	c
R4	K. C. bridge	1.75 ± 0.71	a				
R5	Sidhnai barrage	1.54 ± 0.55	e				
SE:		0.0051				0.0182	
Means For:	First year	1.07 ± 0.12	b			1.13 ± 0.09	b
	Second year	2.25 ± 0.12	a			2.61 ± 0.10	a
Sediments (μg g^{-1} ± SD)							
R1	Baloki headworks	170.76 ± 9.94	b	**T1**	Degh Nulla	189.57 ± 8.49	c
R2	Syedwala	208.49 ± 24.34	a	**T2**	Sammundri M.D.	237.40 ± 36.62	a
R3	Mari Pattan	146.40 ± 21.49	d	**T3**	Sukhrawa M.D.	206.33 ± 2.46	b
R4	K. C. bridge	94.80 ± 67.48	e				
R5	Sidhnai barrage	149.60 ± 4.68	c				
SE :		1.5320				0.7248	
Means For :	First year	168.01 ± 14.04	a			226.95 ± 33.57	a
	Second year	140.02 ± 66.60	b			195.25 ± 10.11	b
Plankton (μg g^{-1} ± SD)							
R1	Baloki headworks	30.87 ± 27.03	d	**T1**	Degh Nulla	41.17 ± 34.16	a
R2	Syedwala	29.20 ± 25.90	e	**T2**	Sammundri M.D.	24.02 ± 15.78	c
R3	Mari Pattan	33.49 ± 29.85	a	**T3**	Sukhrawa M.D.	34.19 ± 29.34	b
R4	K. C. bridge	32.76 ± 28.53	b				
R5	Sidhnai barrage	32.51 ± 27.57	c				
SE :		0.1431				0.2226	
Means For :	First year	3.99 ± 0.56	b			6.71 ± 1.40	b
	Second year	59.54 ± 2.84	a			59.56 ± 14.78	a

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

Table: 22. Manganese toxicity in the river and effluent discharging tributaries.

River stations				Tributaries			
Water (mg L^{-1} ± SD)							
R1	Baloki headworks	2.70 ± 0.72	e	**T1**	Degh Nulla	4.72 ± 0.31	b
R2	Syedwala	3.29 ± 1.54	d	**T2**	Sammundri M.D.	4.83 ± 0.52	a
R3	Mari Pattan	4.68 ± 0.19	b	**T3**	Sukhrawa M.D.	4.48 ± 0.07	c
R4	K. C. bridge	5.02 ± 0.07	a				
R5	Sidhnai barrage	3.56 ± 0.13	c				
SE:		0.0506				0.0182	
Means For:	First year	4.35 ± 0.66	a			4.42 ± 0.10	b
	Second year	3.35 ± 1.32	b			4.93 ± 0.39	a
Sediments (μg g^{-1} ± SD)							
R1	Baloki headworks	1661.06 ± 25.49	b	**T1**	Degh Nulla	1637.22 ± 143.76	b
R2	Syedwala	1425.54 ± 47.91	d	**T2**	Sammundri M.D.	1763.49 ± 213.52	a
R3	Mari Pattan	1571.56 ± 231.58	c	**T3**	Sukhrawa M.D.	371.48 ± 78.47	c
R4	K. C. bridge	1814.59 ± 575.15	a				
R5	Sidhnai barrage	1571.93 ± 126.22	c				
SE :		15.9200				6.9840	
Means For :	First year	1749.51 ± 344.84	a			1350.31 ± 751.90	a
	Second year	1468.38 ± 188.25	b			1164.45 ± 505.75	b
Plankton (μg g^{-1} ± SD)							
R1	Baloki headworks	441.94 ± 77.31	b	**T1**	Degh Nulla	455.87 ± 132.42	a
R2	Syedwala	374.38 ± 137.00	e	**T2**	Sammundri M.D.	456.18 ± 79.94	a
R3	Mari Pattan	393.51 ± 135.87	d	**T3**	Sukhrawa M.D.	309.10 ± 65.66	b
R4	K. C. bridge	429.10 ± 99.95	c				
R5	Sidhnai barrage	449.58 ± 79.59	a				
SE :		1.6040				1.3430	
Means For :	First year	311.76 ± 54.69	b			314.38 ± 54.60	b
	Second year	523.64 ± 7.33	a			499.72 ± 90.90	a

Means with similar letters in a single column are statistically similar at $p < 0.05$
M.D. = main drain

Table: 23. **Mean values for physico–chemical parameters (± SD) in different effluent discharging tributaries and the river.**

River Site Sampling Stations				Tributaries			
Water Temperature (°C) :							
R1	Baloki headworks	22.38 ± 0.10	c	**T1**	Degh Nulla	26.57 ± 0.34	b
R2	Syedwala	22.57 ± 0.12	c	**T2**	Sammundri M.D.	28.10 ± 0.04	a
R3	Mari Pattan	23.68 ± 0.12	a	**T3**	Sukhrawa M.D.	26.17 ± 0.35	c
R4	K. C. bridge	23.91 ± 0.06	a				
R5	Sidhnai barrage	23.09 ± 0.09	b				
SE:		0.4524				0.3898	
Means For:	First year	23.13 ± 0.56	b			26.75 ± 0.98	b
	Second year	23.22 ± 0.58	a			27.14 ± 0.72	a
Water pH :							
R1	Baloki headworks	7.60 ± 0.01	a	**T1**	Degh Nulla	7.48 ± 0.05	b
R2	Syedwala	7.53 ± 0.03	b	**T2**	Sammundri M.D.	7.81 ± 0.11	a
R3	Mari Pattan	7.60 ± 0.05	a	**T3**	Sukhrawa M.D.	7.88 ± 0.08	a
R4	K. C. bridge	7.59 ± 0.04	a				
R5	Sidhnai barrage	7.58 ± 0.03	a				
SE :		0.0506				0.1150	
Means For :	First year	7.60 ± 0.04	a			7.66 ± 0.14	b
	Second year	7.56 ± 0.04	b			7.78 ± 0.22	a
Dissolved Oxygen (mg L^{-1}) :							
R1	Baloki headworks	5.82 ± 0.12	e	**T1**	Degh Nulla	1.07 ± 0.40	b
R2	Syedwala	6.54 ± 0.68	c	**T2**	Sammundri M.D.	0.24 ± 0.10	c
R3	Mari Pattan	6.96 ± 0.05	a	**T3**	Sukhrawa M.D.	1.99 ± 0.07	a
R4	K. C. bridge	6.32 ± 0.44	d				
R5	Sidhnai barrage	6.83 ± 0.35	b				
SE :		0.1239				0.0996	
Means For :	First year	6.36 ± 0.50	b			1.28 ± 0.70	a
	Second year	6.63 ± 0.60	a			0.92 ± 0.77	b

Continued ....

Continued Table 23

River Site Sampling Stations				Tributaries			
Electrical conductivity (µS) :							
R1	Baloki headworks	422.54 ± 34.62	e	T1	Degh Nulla	10568.77 ± 5950.54	a
R2	Syedwala	433.76 ± 57.35	d	T2	Sammundri M.D.	5575.06 ± 1312.51	b
R3	Mari Pattan	667.42 ± 79.87	b	T3	Sukhrawa M.D.	2807.55 ± 503.04	c
R4	K. C. bridge	798.88 ± 92.42	a				
R5	Sidhnai barrage	612.36 ± 4.41	c				
SE:		6.0130				213.1000	
Means For:	First year	640.32 ± 161.80	a			8905.24 ± 5578.52	a
	Second year	533.67 ± 130.07	b			3729.02 ± 1017.90	b
Total hardness (mg L^{-1}) :							
R1	Baloki headworks	141.25 ± 18.10	d	T1	Degh Nulla	914.28 ± 223.02	a
R2	Syedwala	134.09 ± 10.42	e	T2	Sammundri M.D.	453.56 ± 3.27	b
R3	Mari Pattan	180.58 ± 19.48	a	T3	Sukhrawa M.D.	312.43 ± 17.18	c
R4	K. C. bridge	166.84 ± 9.68	b				
R5	Sidhnai barrage	153.78 ± 4.63	c				
SE :		2.6500				6.8750	
Means For :	First year	167.70 ± 19.11	a			480.68 ± 162.69	b
	Second year	142.92 ± 16.39	b			639.50 ± 355.49	a
Magnesium (mg L^{-1}) :							
R1	Baloki headworks	110.67 ± 19.09	d	T1	Degh Nulla	867.98 ± 118.32	a
R2	Syedwala	101.81 ± 15.18	e	T2	Sammundri M.D.	366.41 ± 6.10	b
R3	Mari Pattan	137.53 ± 24.02	a	T3	Sukhrawa M.D.	253.29 ± 4.89	c
R4	K. C. bridge	133.79 ± 20.06	b				
R5	Sidhnai barrage	120.50 ± 7.74	c				
SE :		1.0400				4.8210	
Means For :	First year	138.06 ± 16.80	a			538.74 ± 319.87	a
	Second year	103.65 ± 12.00	b			453.04 ± 214.71	b

Means with similar letters in a single column are statistically similar at $p < 0.05$.
M.D. = main drain

Table: 24. Relationships between river and tributaries for the toxicity of metals in water .

Dependent Variable (µg g^{-1})	Regression Equation	R^2
Iron in river water	= 1.28 + 0.7113 ** (Iron in tributary water)	0.6286
	SE 0.1876	
Zinc in river water	= 0.34 + 0.7266 ** (Zinc in tributary water)	0.7637
	SE 0.1310	
Lead in river water	= 0.8361 + 0.0418 $^{N.S.}$ (Lead in tributary water)	0.0876
	SE 0.1015	
Nickel in river water	= 0.31 + 0.7258 ** (Nickel in tributary water)	0.8660
	SE 0.0894	
Manganese in river water	= 1.85 + 0.4273 * (Manganese in tributary water)	0.4517
	SE 0.1799	

**** = Significant at $p < 0.01$; * = Significant at $p < 0.05$; N.S. = non significant**

Table: 25. Regression of iron toxicity of river and tributary ecosystems on the physico-chemical variables.

Dependent Variable	Regression Equation	R^2
RIVER:		
Iron in water (mg L^{-1})	$Y = 12.25 - 0.0231^{**}$ (E.C.) $+ 0.3685^{**}$ (Temp.)	0. 8673
	SE 0.0041 0.0805	
Iron in sediments (µg g^{-1})	No variables meet the criteria.	
Iron in plankton (µg g^{-1})	$Y = 14019.05 - 14.7624^{*}$ (E.C.)	- 0.4759
	SE 5.8169	
TRIBUTARIES:		
Iron in water (mg L^{-1})	$Y = 1.59 - 0.006^{**}$ (E.C.) $+ 0.4020^{**}$ (Temp.)	0.5861
	SE 0.0001 0.0779	
Iron in sediments (µg g^{-1})	$Y = 25664.17 - 0.9427^{**}$ (E.C.)	- 0. 5858
	SE 0.2781	
Iron in plankton (µg g^{-1})	$Y = 6066.23 - 1.0704^{**}$ (E.C.) $+ 293.1732^{**}$ (Temp.)	0. 6714
	SE 0.1670 77.5987	

E.C. = electrical conductivity (µS) ; Temp. = water temperature (°C) ; ** = significant at $p < 0.01$;

*** = significant at $p < 0.05$**

Table: 26. **Regression of zinc toxicity of river and tributary ecosystems on the physico-chemical variables.**

Dependent Variable	Regression Equation	R^2
RIVER:		
Zinc in water (mg L^{-1})	$Y = 1.24 - 0.0017^{*}$ (E.C.) $+ 0.0896^{**}$ (Temp.)	0. 6771
	SE 0.0007 0.0155	
Zinc in sediments (µg g^{-1})	$Y = 1444.61 + 0.2451^{*}$ (E.C.) $- 170.0498^{**}$ (pH)	0.4526
	SE 0.0948 48.5753	
Zinc in plankton (µg g^{-1})	$Y = 496.60 - 0.5647^{**}$ (E.C.)	- 0.5398
	SE 0.1877	
TRIBUTARIES:		
Zinc in water (mg L^{-1})	$Y = 0.66 + 0.0009^{N.S.}$ (T.H.) $- 0.00006^{N.S.}$ (E.C.) $+ 0.0717^{**}$ (Temp.)	0.6124
	SE 0.0005 0.00003 0.0165	
Zinc in sediments (µg g^{-1})	$Y = 224.58 + 0.0303^{**}$ (E.C.)	0. 7611
	SE 0.0055	
Zinc in plankton (µg g^{-1})	$Y = 371.24 + 0.3302^{*}$ (T.H.) $- 0.0470^{**}$ (E.C.)	0. 6264
	SE 0.1371 0.0087	

E.C. = electrical conductivity (µS) ; Temp. = water temperature (°C) ; T.H. = total hardness (mg L^{-1});

**** = significant at $p < 0.01$; * = significant at $p < 0.05$; N. S. = non significant**

Table: 27. Regression of lead toxicity of river and tributary ecosystems on the physico-chemical variables.

Dependent Variable	Regression Equation	R^2
RIVER:		
Lead in water (mg L^{-1})	No variables meet the criteria.	
Lead in sediments (µg g^{-1})	Y = 440.35 + 0.0360 (E.C.) N.S. - 42.8112 (pH) ** – 1.9683 (Temp.) **	0.5531
	SE 0.0195 12.0700 0.4718	
Lead in plankton (µg g^{-1})	Y = 59.86 – 0.0684 (E.C.) *	- 0.4465
	SE 0.0292	
TRIBUTARIES:		
Lead in water (mg L^{-1})	Y = 0.56 - 0.0001 (E.C.) ** + 0.0458 (Temp.) **	0.5176
	SE 0.00002 0.0117	
Lead in sediments (µg g^{-1})	No variables meet the criteria.	
Lead in plankton (µg g^{-1})	Y = 41.63 - 0.0035 (E.C.) **	- 0. 6174
	SE 0.0001	

E.C. = electrical conductivity (µS) ; Temp. = water temperature (°C) ** = significant at p < 0.01 ; * = significant at p < 0.05 ; N. S. = non significant

Table: 28. Regression of nickel toxicity of river and tributary ecosystems on the physico-chemical variables.

Dependent Variable	Regression Equation	R^2
RIVER:		
Nickel in water (mg L^{-1})	No variables meet the criteria.	
Nickel in sediments (µg g^{-1})	Y = -18.97 + 0.1453** (E.C.) + 3.7982** (Temp.)	0.7494
	SE 0.0430 0.8541	
Nickel in plankton (µg g^{-1})	Y = 106.83 – 0.1284 N.S. (E.C.)	– 0.4816
	SE 0.0498	
TRIBUTARIES:		
Nickel in water (mg L^{-1})	Y = 1.4417 + 0.0012* (T.H.) - 0.0001** (E.C.) + 0.332 N.S. (Temp.)	0.6181
	SE 0.0005 0.00003 0.0189	
Nickel in sediments (µg g^{-1})	Y = 162.14 + 0.0078** (E.C.)	0.4943
	SE 0.0029	
Nickel in plankton (µg g^{-1})	Y = 75.17 - 0.0067** (E.C.)	- 0.7187
	SE 0.0014	

E.C. = electrical conductivity (µS) ; Temp. = water temperature (°C) ; T.H. = total hardness (mg L^{-1});

**** = significant at $p < 0.01$; * = significant at $p < 0.05$; N. S. = non significant**

Table: 29. Regression of manganese toxicity of river and tributary ecosystems on the physico-chemical variables.

Dependent Variable	Regression Equation	R^2
RIVER:		
Manganese in water (mg L^{-1})	$Y = 1.38 + \overset{**}{0.1070}$ (Temp.)	0.5841
	SE 0.0317	
Manganese in sediments (µg g^{-1})	No variables meet the criteria.	
Manganese in plankton (µg g^{-1})	$Y = 977.14 - \overset{**}{1.2119}$ (E.C.) $+ \overset{N.S.}{6.3390}$ (Temp.)	0.7108
	SE 0.1841 3.6543	
TRIBUTARIES:		
Manganese in water (mg L^{-1})	$Y = 0.99 + \overset{*}{0.0017}$ (T.H.) $+ \overset{**}{0.1035}$ (Temp.)	0.7056
	SE 0.0006 0.0191	
Manganese in sediments (µg g^{-1})	$Y = 1181.86 + \overset{**}{0.0687}$ (E.C.) $- \overset{**}{320.1508}$ (D.O.)	0.5127
	SE 0.0160 97.9182	
Manganese in plankton (µg g^{-1})	$Y = 319.01 + \overset{**}{0.3658}$ (T.H.) $- \overset{**}{0.0185}$ (E.C.)	0.5978
	SE 0.0840 0.0053	

E.C. = electrical conductivity (µS) ; Temp. = water temperature (°C) ; T.H. = total hardness (mg L^{-1}); D.O. = dissolved oxygen (mg L^{-1}); ** = significant at $p < 0.01$; * = significant at $p < 0.05$; N. S. = non significant

Table: 30. Relationships between water and sediments for the uptake and accumulation of metals in the river and tributaries .

Dependent Variable ($\mu g\ g^{-1}$)	Regression Equation	R^2
RIVER :		
Iron in sediments	= 12851.26 + 310.3974 (Iron in water) N.S. SE 221.3284	0.0821
Zinc in sediments	= 218.51 + 35.0280 (Zinc in water) N.S. SE 18.6815	0.1378
Lead in sediments	= 92.48 – 1.2809 (Lead in water) N.S. SE 12.7019	0.0215
Nickel in sediments	= 179.29 – 15.2156 (Nickel in water) N.S. SE 9.4537	0.1053
Manganese in sediments	= 1450.40 + 89.4240 (Manganese in water) N.S. SE 213.3470	0.0890
TRIBUTARIES:		
Iron in sediments	= 17628.79 +250.4483 (Iron in water) N.S. SE 308.2682	0.1707
Zinc in sediments	= 467.08 – 19.3113 (Zinc in water) N.S. SE 38.4481	0.1065
Lead in sediments	= 104.70 + 7.5376 (Lead in water) N.S. SE 6.8429	0.0523
Nickel in sediments	= 225.04 – 7.6206 (Nickel in water) N.S. SE 13.3003	0.0149
Manganese in sediments	= 1146.47 + 23.3461 (Manganese in water) N.S. SE 63.6332	0.0061

N.S. = non significant

Table: 31. Relationships between water and plankton for the accumulation of metals in the river and tributaries .

Dependent Variable ($\mu g\ g^{-1}$)	Regression Equation	R^2
RIVER :		
Iron in Plankton	** = 1826.35 + 486.8767 (Iron in water) SE 146.6018	0.3339
Zinc in plankton	N.S. = 38.47 + 55.1610 (Zinc in water) SE 34.0503	0.1066
Lead in plankton	N.S. = 25.10 – 6.0184 (Lead in water) SE 15.1091	0.0846
Nickel in plankton	** = - 30.4317 + 37.5217 (Nickel in water) SE 4.2782	0.7776
Manganese in plankton	N.S. = 4440.32 – 6.9210 (Manganese in water) SE 35.7018	0.0413
TRIBUTARIES:		
Iron in plankton	** = 1247.01 + 699.0816 (Iron in water) SE 85.9416	0.6254
Zinc in plankton	N.S. = - 0.87 + 96.6018 (Zinc in water) SE 59.7339	0.1062
Lead in plankton	* = - 0.66 +17.4527 (Lead in water) SE 7.1369	0.2137
Nickel in plankton	** = - 21.17 + 29.3711 (Nickel in water) SE 4.7935	0.6305
Manganese in plankton	N.S. = 259.16 + 31.5110 (Manganese in water) SE 23.9409	0.0730

**** = Significant at $p < 0.01$; * = Significant at $p < 0.05$; N.S. = non significant**

Table: 32. Relationships between plankton and sediments for the uptake and accumulation of metals in the river and tributaries .

Dependent Variable (µg g^{-1})	Regression Equation	R^2
RIVER :		
Iron in Plankton	** = -2435.71 + 0.5164 (Iron in sediments) SE 0.1239	0.4411
Zinc in plankton	N.S. = 145.31 + 0.0680 (Zinc in sediments) SE 0.3815	0.0380
Lead in plankton	N.S. = 40.69 - 0.2290 (Lead in sediments) SE 0.2497	0.1918
Nickel in plankton	* = 92.83 - 0.3972 (Nickel in sediments) SE 0.1740	0.1915
Manganese in plankton	N.S. = 446.59 – 0.0184 (Manganese in sediments) SE 0.0354	0.1100
TRIBUTARIES:		
Iron in plankton	** = - 4399.90 + 0.5844 (Iron in sediments) SE 0.1041	0.5887
Zinc in plankton	** = 792.38 – 1.2824 (Zinc in sediments) SE 0.2159	0.6159
Lead in plankton	* = - 40.12 + 0.5248 (Lead in sediments) SE 0.2170	0.4584
Nickel in plankton	N.S. = 60.31 – 0.1291 (Nickel in sediments) SE 0.1234	0:0474
Manganese in plankton	N.S. = 541.74 – 0.1074 (Manganese in sediments) SE 0.798	0.0760

**** = Significant at p < 0.01 ; * = Significant at p < 0.05 ; N. S . = non significant**

Table: 33. **Flow patterns of metals in the River and tributary's ecosystem.**

Dependent Variable (µg g^{-1})	Regression Equation	R^2
RIVER ECOSYSTEM:		
Iron in Plankton	= -2435.71 + 0.5164** (Iron in sediments) SE 0.1239	0.4411
	= - 3601.80 + 0.4224** (Iron in sediments) + 355.7701** (Iron in water) SE 0.1113 126.6440	0.7777
Zinc in Plankton	= No variables meet the criteria.	
Lead in Plankton	= No variables meet the criteria.	
Nickel in Plankton	= - 30.4317 + 37.5217** (Nickel in water) SE 4.2782	0.7776
Manganese in Plankton	= No variables meet the criteria.	
TRIBUTARY ECOSYSTEM:		
Iron in Plankton	= - 4399.89 + 0.5844** (Iron in sediments) SE 0.1041	0.5887
	= - 7888.78 + 0.5182** (Iron in sediments) + 569.2914** (Iron in water) SE 0.0674 98.8357	0.8406
Zinc in Plankton	= 792.38 – 1.2824** (Zinc in sediments) SE 0.2159	0.6159
	= 578.17 – 1.2397** (Zinc in sediments) + 72.6615 N.S. (Zinc in water) SE 0.2043 37.06	0.6753
Lead in Plankton	= - 0.66 + 17.4527* (Lead in water) SE 7.1369	0.4623
	= - 45.27 + 0.4261* (Lead in sediments) + 14.2411* (Lead in water) SE 0.2077 6.8488	0.5873
Nickel in Plankton	= - 21.17 + 29.3711** (Nickel in water) SE 4.7938	0.6305
Manganese in Plankton	= No variables meet the criteria.	

**** = significant at $p < 0.01$; * = significant at $p < 0.05$; N. S. = non significant**

Sidhnai Barrage	Catla catla	3	14
	Labeo rohita	18	7
	Cirrhina mrigala	10	8

Sidhnai Barrage	<u>Catla</u> <u>catla</u>	3	14
	<u>Labeo</u> <u>rohita</u>	18	7
	<u>Cirrhina</u> <u>mrigala</u>	10	8

Sidhnai Barrage	<u>Catla</u> <u>catla</u>	3	14[illegible]
	<u>Labeo</u> <u>rohita</u>	18	7[illegible]
	<u>Cirrhina</u> <u>mrigala</u>	10	8[illegible]

TABLE: 37 Concentration of nickel ($\mu g\ g^{-1}$) in fish body.

SAMPLING STATION	FISH SPECIES	S. SIZE (No.)	AVERAGE WEIGHT (g)	METAL CONCENTRATION IN FISH BODY ($\mu g\ g^{-1}$)			
				Muscle	Gills	Liver	Kidney
Baloki Headworks	Catla catla	3	619.54 ± 49.87	1.98 ± 0.11	3.90 ± 0.33	10.98 ± 0.45	4.02 ± 0.42
	Labeo rohita	19	1065.90 ± 120.25	1.44 ± 0.04	3.66 ± 0.56	9.65 ± 1.02	3.76 ± 0.54
	Cirrhina mrigala	11	590.00 ± 101.34	2.10 ± 0.02	3.80 ± 0.32	9.79 ± 0.23	3.90 ± 0.44
Sidhnai Barrage	Catla catla	3	1475.20 ± 44.25	1.67 ± 0.23	2.63 ± 0.32	7.95 ± 0.54	4.26 ± 0.24
	Labeo rohita	18	778.05 ± 78.35	1.56 ± 0.21	3.26 ± 0.55	10.01 ± 1.11	3.88 ± 0.44
	Cirrhina mrigala	10	800.65 ± 84.25	1.65 ± 0.34	3.43 ± 0.04	8.33 ± 1.03	4.00 ± 0.65

Sidhnai Barrage	<u>Catla</u> <u>catla</u>	3	14[illegible]
	<u>Labeo</u> <u>rohita</u>	18	7[illegible]
	<u>Cirrhina</u> <u>mrigala</u>	10	8[illegible]

TABLE: 39 **Accumulation of metals in different organs of three fish species.**

VARIABLE (S.O.V.)	MEAN SQUARES				
	IRON	ZINC	LEAD	NICKEL	MANGANESE
Fish organs	(P<0.01) 136971.66	(P<0.01) 2841.02	(P<0.01) 37.42	(P<0.01) 66.95	(P<0.01) 91.51
Fish species	NS 895.89	NS 231.75	(P<0.01) 31.70	NS 0.005	NS 8.15
Sites of fish collection	(P<0.05) 299.95	NS 189.06	NS 11.00	(P<0.05) 1.68	NS 16.02

COMPARISON OF MEANS ($\mu g\ g^{-1}$)

VARIABLE	IRON	ZINC	LEAD	NICKEL	MANGANESE
FISH ORGANS:					
Fish Muscle	69.49 d	75.42 c	7.58 b	1.73 c	9.02 b
Fish Gills	291.40 b	83.20 bc	12.55 a	3.45 b	11.27 b
Fish Liver	431.30 a	124.90 a	12.54 a	9.45 a	17.49 a
Fish Kidney	213.60 c	91.64 b	9.13 b	3.97 b	15.70 a
FISH SPECIES:					
Catla catla	260.86 a	98.90 a	12.29 a	4.67 a	14.39 a
Labeo rohita	253.52 a	94.28 a	10.72 a	4.65 a	13.35 a
Cirrhina mrigala	239.99 a	88.17 a	8.34 b	4.62 a	12.37 a
SITE OF FISH COLLECTION:					
Baloki headworks	263.45 a	96.59 a	11.13 a	4.91 a	14.19 a
Sidhnai barrage	239.47 b	90.98 a	9.77 a	4.39 b	12.55 a

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

	Catla Catla	7	690.22 ± 70
Sidhnai Barrage	*Labeo rohita*	13	845.99 ± 88
	Cirrhina mrigala	12	805.25 ± 72

Means with similar letters in a single column are statistic

	Catla Catla	7	690.22 ± 70
Sidhnai Barrage	*Labeo rohita*	13	845.99 ± 88
	Cirrhina mrigala	12	805.25 ± 72.

Means with similar letters in a single column are statistica

Sidhnai Barrage	*Catla Catla*	7	690.22 ± 70.
	Labeo rohita	13	845.99 ± 88.
	Cirrhina mrigala	12	805.25 ± 72.

Means with similar letters in a single column are statistical

Table : 43. Concentration of nickel ($\mu g\ g^{-1}$) in fish body.

SAMPLING STATION	FISH SPECIES	S. SIZE (No.)	AVERAGE WEIGHT (g)	METAL CONCENTRATION IN FISH BODY ($\mu g\ g^{-1}$)					
				Scale	Skin	Muscle	Gills	Liver	Kidney
Baloki Headworks	*Catla Catla*	6	580.09 ± 69.88	5.29 ± 0.01	9.30 ± 0.30	3.53 ± 0.38	4.07 ± 0.13	8.46 ± 0.45	2.52 ± 0.38
	Labeo rohita	14	725.84 ± 102.28	4.40 ± 0.41	9.15 ± 0.15	2.91 ± 0.03	4.66 ± 0.34	6.87 ± 0.49	2.57 ± 0.43
	Cirrhina mrigala	10	700.62 ± 91.22	4.79 ± 0.07	7.69 ± 0.16	3.76 ± 0.12	3.44 ± 0.40	5.82 ± 0.02	2.23 ± 0.09
Sidhnai Barrage	*Catla Catla*	7	690.22 ± 70.22	6.27 ± 0.06	9.11 ± 0.11	3.77 ± 0.03	4.90 ± 0.10	8.05 ± 0.21	2.42 ± 0.07
	Labeo rohita	13	845.99 ± 88.25	5.70 ± 0.35	8.64 ± 0.30	3.22 ± 0.21	4.32 ± 0.07	8.84 ± 0.10	3.10 ± 0.16
	Cirrhina mrigala	12	805.25 ± 72.00	4.88 ± 0.04	8.60 ± 0.34	3.17 ± 0.28	4.04 ± 0.04	6.06 ± 0.15	3.27 ± 0.11

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

Table : 44. Concentration of manganese ($\mu g\ g^{-1}$) in fish body.

SAMPLING STATION	FISH SPECIES	S. SIZE (No.)	AVERAGE WEIGHT (g)	METAL CONCENTRATION IN FISH BODY ($\mu g\ g^{-1}$)					
				Scale	Skin	Muscle	Gills	Liver	Kidney
Baloki Headworks	*Catla Catla*	6	580.09 ± 69.88	20.30 ± 5.30	18.05 ± 0.95	9.50 ± 0.50	43.45 ± 3.15	18.73 ± 0.47	16.33 ± 1.94
	Labeo rohita	14	725.84 ± 102.28	28.75 ± 1.05	13.70 ± 1.30	9.48 ± 0.83	43.45 ± 7.35	11.81 ± 0.54	12.33 ± 2.03
	Cirrhina mrigala	10	700.62 ± 91.22	15.01 ± 0.20	9.08 ± 0.28	10.68 ± 0.48	31.30 ± 1.05	14.01 ± 0.24	17.28 ± 0.06
Sidhnai Barrage	*Catla Catla*	7	690.22 ± 70.22	25.60 ± 2.10	12.83 ± 0.43	9.71 ± 0.40	37.15 ± 1.05	34.06 ± 1.67	13.85 ± 0.06
	Labeo rohita	13	845.99 ± 88.25	22.40 ± 5.30	13.68 ± 1.30	11.53 ± 0.88	49.67 ± 1.14	16.29 ± 1.91	14.17 ± 1.03
	Cirrhina mrigala	12	805.25 ± 72.00	37.15 ± 1.05	10.51 ± 0.16	10.24 ± 1.09	39.10 ± 0.90	14.55 ± 0.70	13.85 ± 0.43

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

Table: 45. Accumulation of metals in different organs of three fish species.

VARIABLE (S. O. V.)	MEAN SQUARES IRON	ZINC	LEAD	NICKEL	MANGANESE
Fish organs	($p < 0.01$) 511961.01	($p < 0.01$) 72950.82	($p < 0.01$) 246.76	($p < 0.01$) 66.47	($p < 0.01$) 1509.00
Fish species	($p < 0.01$) 7842.74	($p < 0.01$) 25179.10	($p < 0.01$) 29.44	($p < 0.01$) 4.27	($p < 0.01$) 58.39
Sites of fish collection	($p < 0.01$) 154409.57	($p < 0.01$) 38322.96	($p < 0.01$) 18.97	($p < 0.01$) 2.64	($p < 0.01$) 102.96

COMPARISON OF MEANS ($\mu g\ g^{-1}$)

VARIABLE	IRON	ZINC	LEAD	NICKEL	MANGANESE
FISH ORGANS:					
Fish Scale	167.00 c	174.70 c	6.85 cd	5.22 c	24.87 b
Fish Skin	194.30 c	115.00 d	6.36 d	8.75 a	12.97 d
Fish muscle	118.50 d	94.64 e	8.19 c	3.39 e	10.19 e
Fish Gills	455.10 b	210.40 b	10.58 b	4.24 d	40.68 a
Fish Liver	639.70 a	312.10 a	16.91 a	7.35 b	18.23 c
Fish Kidney	440.60 b	205.60 b	15.64 a	2.68 f	14.63 d
FISH SPECIES:					
Catla catla	346.30 a	216.70 a	11.88 a	5.64 a	21.62 a
Labeo rohita	346.30 a	152.00 c	10.73 b	5.36 b	20.60 a
Cirrhina mrigala	315.00 b	187.50 b	9.66 b	4.81 c	18.56 b
SITE OF FISH COLLECTION:					
Baloki headworks	289.55 b	162.33 b	10.24 b	5.08 b	19.07 b
Sidhnai barrage	382.17 a	208.47 a	11.27 a	5.46 a	21.46 a

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

Table : 46. Relationships among fish organs for the uptake and accumulation of metals from water, sediments and plankton.

Variables	Metal concentration in fish organs							
	Scale	Skin	Muscle	Gills	Liver	Kidney	Water	Sediments
Iron:								
Fish Skin	- 0.5184							
Fish Muscle	- 0.1933	0.8104						
Fish Gills	- 0.5871	- 0.1761	- 0.0487					
Fish Liver	- 0.1234	- 0.6488	- 0.9497	0.2270				
Fish Kidney	- 0.0316	- 0.7152	- 0.9744	0.1982	0.9953			
Iron in water	0.0831	0.6831	0.9616	- 0.2221	- 0.9989	- 0.9986		
Iron in Sediments	- 0.0457	- 0.6986	- 0.9713	0.1908	0.9969	0.9997	- 0.9992	
Iron in Plankton	0.0466	0.6955	0.9710	- 0.1866	- 0.9970	- 0.9996	0.9992	- 0.9999
Zinc:								
Fish Skin	0.7489							
Fish Muscle	0.1881	0.5671						
Fish Gills	- 0.8140	- 0.9927	- 0.4835					
Fish Liver	- 0.7333	- 0.9978	- 0.6204	0.9847				
Fish Kidney	- 0.9072	- 0.9225	- 0.5593	0.9390	0.9266			
Zinc in water	- 0.8434	- 0.9861	- 0.5388	0.9931	0.9836	0.9716		
Zinc in Sediments	- 0.8512	- 0.9833	- 0.5372	0.9915	0.9810	0.9751	0.9999	
Zinc in Plankton	- 0.8239	- 0.9906	- 0.5610	0.9933	0.9895	0.9663	0.9993	0.9993

Critical Value (1 – tail, 0.05) = +/- 0.9282

Continued..................

Continued Table 46

Variables	Scale	Skin	Muscle	Gills	Liver	Kidney	Water	Sediments
	Metal concentration in fish organs							
Lead:								
Fish Skin	0.9709							
Fish Muscle	0.9067	0.8717						
Fish Gills	- 0.3685	- 0.5633	- 0.1535					
Fish Liver	- 0.4835	- 0.6773	- 0.4540	0.8839				
Fish Kidney	0.3957	0.5831	0.1647	- 0.9987	- 0.8695			
Lead in water	0.5033	0.6775	0.2796	- 0.9885	- 0.8887	0.9926		
Lead in Sediments	- 0.5068	- 0.6795	- 0.2800	0.9876	0.8849	- 0.9922	- 0.9999	
Lead in Plankton	- 0.4954	- 0.6688	- 0.2641	0.9890	0.8789	- 0.9938	- 0.9998	0.9998
Nickel:								
Fish Skin	0.2020							
Fish Muscle	- 0.0440	- 0.6683						
Fish Gills	0.9138	- 0.2068	0.2827					
Fish Liver	0.9294	- 0.1702	0.2432	0.9991				
Fish Kidney	0.8385	- 0.2817	0.4881	0.9715	0.9626			
Nickel in water	- 0.9814	- 0.3860	0.1673	- 0.8207	- 0.8424	- 0.7366		
Nickel in Sediments	- 0.8872	- 0.3380	- 0.1706	- 0.7775	- 0.7876	- 0.7950	0.9047	
Nickel in Plankton	0.9575	0.3973	- 0.0351	0.8064	0.8241	0.7651	- 0.9810	- 0.9694

Critical Value (1 – tail, 0.05) = +/- 0.9282

Continued..................

Continued Table 46

Variables	Metal concentration in fish organs							
	Scale	Skin	Muscle	Gills	Liver	Kidney	Water	Sediments
Manganese:								
Fish Skin	- 0.6873							
Fish Muscle	0.8625	- 0.2765						
Fish Gills	0.8119	- 0.9802	0.4329					
Fish Liver	0.7675	- 0.7564	0.3809	0.8372				
Fish Kidney	- 0.6947	0.9359	- 0.4132	- 0.9117	- 0.5394			
Manganese in water	0.8170	- 0.7566	0.4561	0.8477	0.9965	- 0.5610		
Manganese in Sediments	0.7808	- 0.8514	0.3687	0.9107	0.9871	- 0.6606	0.9840	
Manganese in Plankton	0.7009	- 0.7406	0.2900	0.8104	0.9951	- 0.4987	0.9836	0.9798

Critical Value (1 – tail, 0.05) = +/- 0.9282

APPENDIX TABLES

ppendix Table 1 : **Mean annual metal concentrations (± SD) and physico- chemistry of the river Ravi stretch from Shahdera to Baloki headworks.**

riable	Shahdera Bridge	Baradarri	Sharqpur	Thatta Polianwala	I/B Q. B.Link Canal & Baloki Head	Head Baloki
n :						
ater (mg L^{-1})	6.84 ± 3.70	7.16 ± 4.10	6.02 ± 2.42	7.81 ± 1.78	6.22 ± 2.17	7.42 ± 3.57
diments (µg g^{-1})	14580.10 ± 240.62	18200.25 ± 205.83	15140.81 ± 501.68	14760.39 ± 270.33	13490.48 ± 190.15	17300.23 ± 140.33
nkton (µg g^{-1})	1874.66 ± 48.62	4893.28 ± 160.20	5277.20 ± 94.37	5820.54 ± 82.30	5439.38 ± 43.01	4712.09 ± 54.38
nc :						
ater (mg L^{-1})	0.52 ± 0.16	0.54 ± 0.15	0.88 ± 0.45	0.69 ± 0.25	0.57 ± 0.22	0.71 ± 0.24
diments (µg g^{-1})	79.63 ± 8.99	94.73 ± 7.53	133.60 ± 28.95	99.85 ± 20.11	75.69 ± 24.75	90.00 ± 7.38
nkton (µg g^{-1})	82.96 ± 13.28	85.75 ± 10.10	141.80 ± 11.25	79.52 ± 4.81	62.67 ± 3.77	102.67 ± 5.20
ad :						
ater (mg L^{-1})	0.25 ± 0.05	0.37 ± 0.08	0.67 ± 0.25	0.36 ± 0.13	0.29 ± 0.09	0.27 ± 0.08
diments (µg g^{-1})	133.20 ± 20.31	131.00 ± 16.88	220.10 ± 21.39	225.00 ± 11.06	203.70 ± 10.85	164.30 ± 7.35
nkton (µg g^{-1})	5.74 ± 1.37	4.21 ± 2.01	9.55 ± 3.94	4.71 ± 0.72	5.03 ± 0.58	4.01 ± 0.42
ckel :						
ater (mg L^{-1})	0.46 ± 0.15	0.51 ± 0.20	0.75 ± 0.35	0.58 ± 0.22	0.55 ± 0.20	0.52 ± 0.19
diments (µg g^{-1})	259.00 ± 11.25	431.50 ± 8.02	473.90 ± 18.22	509.00 ± 14.95	431.20 ± 7.34	381.20 ± 6.22
nkton (µg g^{-1})	5.29 ± 0.94	6.10 ± 0.35	9.24 ± 3.01	8.47 ± 2.11	6.86 ± 0.87	6.79 ± 0.32
anganese :						
ater (mg L^{-1})	0.72 ± 0.37	1.42 ± 0.44	1.13 ± 0.48	0.89 ± 0.29	0.73 ± 0.35	0.78 ± 0.28
diments (µg g^{-1})	1505.28 ± 170.32	1710.54 ± 243.82	2072.28 ± 192.32	2112.20 ± 132.98	2188.29 ± 79.63	2065.01 ± 63.00
nkton (µg g^{-1})	220.50 ± 10.35	240.80 ± 12.55	474.80 ± 32.78	482.60 ± 21.21	391.90 ± 24.54	257.70 ± 14.99
ater Temperature (°C)	26.16 ± 5.52	26.27 ± 5.27	26.68 ± 4.84	26.35 ± 4.96	25.16 ± 5.18	25.95 ± 5.25
ater pH	8.12 ± 0.09	8.00 ± 0.16	8.09 ± 0.22	8.30 ± 0.19	8.22 ± 0.09	8.32 ± 0.16
issolved Oxygen (mg L^{-1})	7.27 ± 0.45	6.82 ± 0.41	5.83 ± 0.58	5.64 ± 0.35	7.47 ± 0.57	6.88 ± 0.46
ectrical conductivity (µS)	299.40 ± 61.91	302.90 ± 54.54	522.70 ± 88.64	586.80 ± 188.64	340.60 ± 21.71	298.90 ± 60.17
ater Total Hardness (mg L^{-1})	178.40 ± 25.91	193.40 ± 17.41	215.90 ± 23.74	222.80 ± 46.22	188.10 ± 14.88	191.30 ± 45.57
ater Magnesium (mg L^{-1})	10.48 ± 1.36	12.90 ± 2.55	9.22 ± 1.15	9.47 ± 1.21	9.51 ± 1.21	9.27 ± 0.81

ppendix Table 2 : **Mean annual metal concentrations (± SD) and physico-chemistry of the effluent discharging tributaries at the river stretch from Shahdera bridge to Baloki headworks.**

riable	Farrukhabad Nulla	Munshi Hosp. Nulla	Taj Company Nulla	Bakar Mandi Nulla	Hudiara Nulla	Degh nulla I
on :						
ater (mg L^{-1})	11.89 ± 6.04	5.72 ± 2.29	3.32 ± 1.07	4.27 ± 1.05	3.24 ± 1.01	5.05 ± 1.78
diments (µg g^{-1})	24260.15 ± 871.50	13820.92 ± 200.01	10000.21 ± 164.68	11550.44 ± 210.05	12270.65 ± 270.33	10590.31 ± 137.90
ankton (µg g^{-1})	7351.00 ± 194.65	4592.50 ± 50.21	3505.38 ± 30.94	3083.42 ± 28.52	2995.54 ± 90.11	2300.55 ± 35.92
inc :						
ater (mg L^{-1})	3.92 ± 2.04	1.17 ± 0.06	1.12 ± 0.24	2.17 ± 0.93	1.64 ± 0.60	0.50 ± 0.14
diments (µg g^{-1})	406.50 ± 34.67	184.10 ± 17.35	229.50 ± 22.48	346.80 ± 19.40	242.70 ± 16.23	91.19 ± 14.95
ankton (µg g^{-1})	199.10 ± 22.54	142.20 ± 4.82	199.90 ± 6.81	191.60 ± 14.25	206.00 ± 4.85	129.80 ± 9.64
ead :						
ater (mg L^{-1})	0.83 ± 0.29	0.48 ± 0.09	0.69 ± 0.22	0.78 ± 0.30	0.76 ± 0.16	0.54 ± 0.16
ediments (µg g^{-1})	378.80 ± 34.87	150.70 ± 21.65	159.50 ± 24.87	297.80 ± 31.55	287.20 ± 19.64	209.80 ± 16.16
lankton (µg g^{-1})	11.18 ± 4.05	6.83 ± 1.04	4.05 ± 1.21	5.33 ± 1.73	7.37 ± 2.54	5.91 ± 1.14
ickel :						
ater (mg L^{-1})	2.43 ± 0.27	0.83 ± 0.14	0.90 ± 0.22	1.00 ± 0.19	0.96 ± 0.23	0.69 ± 0.18
ediments (µg g^{-1})	863.04 ± 4.37	469.60 ± 23.21	521.40 ± 28.14	604.50 ± 11.25	731.40 ± 16.77	489.00 ± 21.59
lankton (µg g^{-1})	14.97 ± 1.94	8.31 ± 2.34	10.26 ± 4.21	10.97 ± 3.61	15.95 ± 6.11	8.06 ± 1.38
langanese :						
ater (mg L^{-1})	3.07 ± 0.66	1.46 ± 0.42	1.55 ± 0.44	1.05 ± 0.17	1.49 ± 0.41	1.59 ± 0.91
ediments (µg g^{-1})	2895.23 ± 420.55	3536.40 ± 300.37	3405.39 ± 294.58	2472.55 ± 243.88	3572.84 ± 210.30	2471.92 ± 190.36
lankton (µg g^{-1})	681.20 ± 30.22	746.40 ± 40.58	703.20 ± 34.93	439.30 ± 32.11	741.90 ± 40.53	281.50 ± 13.94
Vater Temperature °C)	28.36 ± 5.52	27.40 ± 5.00	27.78 ± 5.15	28.20 ± 5.61	27.60 ± 5.21	25.48 ± 5.17
Vater pH	7.45 ± 0.25	7.53 ± 0.30	7.31 ± 0.27	7.56 ± 0.37	8.35 ± 0.37	8.21 ± 0.14
Dissolved Oxygen mg L^{-1})	0.97 ± 0.43	2.10 ± 0.78	2.41 ± 0.78	1.97 ± 0.90	0.48 ± 0.42	3.28 ± 0.58
Electrical conductivity µ S)	1038.30 ± 159.56	1338.28 ± 87.87	1167.94 ± 94.72	1174.99 ± 72.63	1983.04 ± 262.20	604.09 ± 128.31
Vater Hardness mg L^{-1})	371.50 ± 37.11	378.50 ± 35.07	316.60 ± 44.81	309.10 ± 30.09	491.80 ± 50.41	216.60 ± 39.32
Vater Magnesium mg L^{-1})	17.65 ± 4.93	18.91 ± 2.50	23.94 ± 2.53	31.24 ± 4.30	36.48 ± 6.01	11.72 ± 1.87

7. _Bacillaria_	31 ±20.12	28 ±26.43	25 ±16.66
8. _Cladophora_	-	-	-
9. _Closterium_	64 ±299.65	12 6 ±10.55	15 ±11.85
10. _Chlorella_	-	-	-
11 _Cyclotella_	12 ±24.99	2 ±6.12	178 ±66.02
12. _Cocconeis_	11 ±15.33	23 ±40.76	18 ±14.21
13. _Cosmarium_	34 ±66.67	32 ±32.09	103 ±45.80

20. <u>Melosira</u>	-	-	-
21. <u>Microcystis</u>	-	-	-
22. <u>Navicula</u>	-	-	10 ±20.28
23. <u>Oscillatoria</u>	-	-	-
24. <u>Pinnularia</u>	9 ±28.55	22 ±10.34	31 ±23.21
25. <u>Synedra</u>	-	-	-
26. <u>Spirulina</u>	45 ±61.03	20 ±33.56	21 ±19.93

2. Brachionus	-	-	-
3. Keratella	-	-	5 ±21.65
4. Polyarthra	-	-	-
5. Cyclops	-	-	-
6. Monnstyla	10 ±26.90	-	-
7. Filinia	9 ±28.21	-	-

Appendix Table 4. Mean annual values for metals toxicity in water, sediments and plankton in the river Ravi stretch from Baloki headworks to Sidhnai barrage and three effluent discharging tributaries.

Variable	Baloki headworks	Syedwala	Mari Pattan	K.C. Bridge	Sidhnai Barrage	Degh Nulla	Sammundri M. Drain	Sukhrawa M. Drain
FIRST YEAR								
Iron :								
Water (mg L^{-1})	4.99 ± 1.69	4.59 ± 1.69	5.80 ± 1.76	4.23 ± 0.75	5.23 ± 1.45	7.61 ± 1.41	6.70 ± 1.83	6.02 ± 2.80
Sediments (µg g^{-1})	12206.17 ±3439.82	12208.33 ± 4349.88	9343.26 ± 2755.02	12744.95 ± 4074.40	11905.50 ± 1769.32	17639.37 ± 4096.42	13257.86 ± 3297.79	16082.00 ± 3071.16
Plankton (µg g^{-1})	3092.47 ± 900.37	1002.47 ± 125.89	2179.46 ± 490.95	2768.54 ± 667.31	3893.48 ± 342.81	3938.38 ± 245.13	4117.67 ± 297.93	2910.76 ± 307.38
Zinc :								
Water (mg L^{-1})	2.21 ± 0.55	2.09 ± 0.92	2.45 ± 1.02	1.96 ± 0.61	1.80 ± 0.92	2.79 ± 0.76	2.53 ± 0.59	1.86 ± 0.69
Sediments (µg g^{-1})	167.59 ± 23.08	396.19 ± 202.28	335.00 ± 81.48	387.21 ± 104.75	196.85 ± 78.49	419.22 ± 107.67	920.41 ± 285.89	294.77 ± 55.89
Plankton (µg g^{-1})	60.28 ± 9.48	48.37 ± 8.49	64.36 ± 14.22	79.39 ± 8.43	48.92 ± 7.25	71.13 ± 9.06	73.01 ± 7.62	60.97 ± 6.06
Lead :								
Water (mg L^{-1})	0.66 ± 0.35	1.00 ± 0.79	0.75 ± 0.21	1.66 ± 0.77	0.62 ± 0.27	0.95 ± 0.41	0.92 ± 0.38	0.51 ± 0.19
Sediments (µg g^{-1})	135.97 ± 21.81	133.29 ± 45.87	78.36 ± 18.44	89.55 ± 17.46	40.83 ± 11.91	78.73 ± 21.67	121.91 ± 13.73	122.81 ± 16.25
Plankton (µg g^{-1})	5.56 ± 1.29	4.30 ± 0.92	4.05 ± 1.01	3.79 ± 0.57	4.51 ± 0.68	6.86 ± 0.81	6.86 ± 1.06	3.95 ± 1.12
Nickel :								
Water (mg L^{-1})	1.30 ± 0.32	0.96 ± 0.21	1.05 ± 0.23	1.03 ± 0.27	0.98 ± 0.34	1.06 ± 0.25	1.25 ± 0.34	1.06 ± 0.17
Sediments (µg g^{-1})	180.69 ± 62.11	184.16 ± 74.86	167.87 ± 46.94	162.28 ± 48.19	145.02 ± 47.93	198.06 ± 70.61	274.02 ± 42.98	208.80 ± 72.54
Plankton (µg g^{-1})	3.84 ± 0.44	3.30 ± 0.64	3.63 ± 0.75	4.23 ± 1.08	4.93 ± 0.74	7.01 ± 0.94	8.25 ± 1.07	4.85 ± 1.58
Manganese :								
Water (mg L^{-1})	3.42 ± 1.63	4.82 ± 0.57	4.87 ± 0.53	4.96 ± 0.92	3.68 ± 1.72	4.41 ± 0.89	4.30 ± 1.13	4.55 ± 1.27
Sediments (µg g^{-1})	1635.99 ± 480.29	1473.41 ± 1257.16	1802.74 ± 664.08	2389.71 ± 794.22	1445.71 ± 352.98	1780.91 ± 573.86	1977.00 ± 668.86	293.01 ± 31.04
Plankton (µg g^{-1})	364.63 ± 19.54	237.34 ± 38.56	257.63 ± 46.70	329.16 ± 62.41	370.00 ± 24.67	323.45 ± 34.60	376.24 ± 36.00	243.45 ± 43.96

Continued ----------------

SECOND YEAR

Iron :		
Water (mg L^{-1})	12.45 ± 10.09	9.21 ± 7.47
Sediments (µg g^{-1})	17069.67 ± 4538.42	17012.67 ± 3630.00
Plankton (µg g^{-1})	12910.27 ± 8833.68	5157.66 ± 2922.91
Zinc :		
Water (mg L^{-1})	2.02 ± 0.75	2.45 ± 0.89
Sediments (µg g^{-1})	192.94 ± 49.39	464.75 ± 191.15
Plankton (µg g^{-1})	236.83 ± 99.70	289.67 ± 115.33

Plankton ($\mu g\ g^{-1}$)	518.48 ± 240.75	510.40 ± 265.17
Water Temperature (°C)	22.21 ± 5.13	22.81 ± 9.94
Water pH	7.62 ± 0.12	7.54 ± 0.13
Dissolved Oxygen ($mg\ L^{-1}$)	5.92 ± 1.17	7.12 ± 2.52
Electrical conductivity (μS)	385.75 ± 77.05	372.42 ± 58.71
Water Hardness ($mg\ L^{-1}$)	125.83 ± 29.29	122.50 ± 24.54
Water Magnesium ($mg\ L^{-1}$)	91.17 ± 25.98	86.17 ± 20.39

APPENDIX TABLE: 5 Planktonic productivity (individuals per litre of water) of river Ravi stretch from Balcki headworks to Sidhnai barrage (First Year).

	RIVER SITE SAMPLING STATIONS					EFFLUENT DISCHARGING TRIBUTARIES		
	R1	R2	R3	R4	R5	T1	T2	T3
a) PHYTOPLANKTON								
1. Aphanothece	290 ±200.32	150 ±99.90	55 ±57.54	80 ±67.33	160 ±111.87	6 ±19.65	12 ±16.25	3 ±16.98
2. Artgrospira	14 ±18.88	20 ±38.70	19 ±23.87	-	10 ±19.65	-	-	6 ±23.76
3. Anabaena	68 ±77.54	65 ±29.03	94 ±19.09	84 ±92.76	59 ±29.04	16 ±19.65	17 ±21.54	11 ±2.33
4. Aphanocapsa	94 ±120.90	140 ±133.55	28 ±55.02	16 ±39.41	34 ±77.42	-	-	9 ±46.08
5. Arthrospira	-	5 ±19.22	4 ±11.03	8 ±22.42	8 ±20.65	5 ±19.19	8 ±36.74	10 ±26.03
6. Bumilleria	34 ±61.23	28 ±39.09	62 ±21.90	84 ±103.34	45 ±43.62	20 ±25.45	14 ±26.75	18 ±42.66
7. Bacillaria	14 ±27.93	29 ±19.23	-	32 ±61.90	45 ±33.32	-	-	-
8. Cladophora	8 ±21.93	11 ±26.54	2 ±20.88	14 ±18.53	- ±11.52	- ±19.65	- ±16.25	- ±16.98
9. Chlorella	5 ±22.90	11 ±44.89	2 ±9.20	14 ±23.60	-	-	-	-
10. Cyclotella	14 ±21.00	42 ±24.66	16 ±40.00	31 ±24.92	9 ±22.05	11 ±22.42	14 ±24.92	18 ±11.00
11. Cosmarium	-	-	-	4 ±22.90	11 ±16.92	-	-	-
12. Denticulla	28 ±34.58	30 ±44.25	41 ±71.25	52 ±57.25	41 ±24.36	5 ±26.41	4 ±14.23	-
13. Dinobryon	-	-	-	-	-	7 ±34.25	5 ±24.58	10 ±25.26
14. Eudorina	14 ±21.25	40 ±55.14	14 ±15.58	18 ±26.25	30 ±14.27	2 ±33.25	-	-
15. Euglena	13 ±22.12	14 ±34.57	24 ±45.20	32 ±28.24	19 ±54.27	11 ±31.21	10 ±24.57	8 ±20.20
16. Melosira	24 ±26.23	11 ±21.02	19 ±41.21	30 ±33.24	26 ±16.14	5 ±20.47	-	11 ±17.88
17. Microcystis	30 ±35.35	19 ±19.14	45 ±33.57	38 ±61.24	20 ±58.57	-	-	-
18. Navicula	20 ±30.30	11 ±16.14	90 ±101.66	49 ±66.34	22 ±26.25	5 ±10.24	4 ±20.14	-
19. Oscillatoria	10 14.15	12 ±19.24	27 ±62.14	-	-	-	-	-
20. Oocystis	11 ±14.24	14 ±19.64	25 ±8.45	6 ±14.21	14 ±10.33	6 ±12.47	4 ±10.21	5 ±11.14
21. Pandorina	19 ±26.25	26 ±24.17	5 ±10.24	9 ±19.57	11 ±14.24	-	-	-
22. Pediastrum	11 ±19.20	26 ±22.13	-	9 ±11.17	10 ±19.64	2 ±11.45	-	-
23. Peridinium	-	-	14 ±10.14	8 ±11.18	-	6 ±17.48	-	9 ±14.27

Continued ....

Continued Table 5

	RIVER SITE SAMPLING STATIONS					EFFLUENT DISCHARGING TRIBUTARIES		
	R1	R2	R3	R4	R5	T1	T2	T3
24. Phacus	4 ±9.45	19 ±22.47	-	-	-	2 ±10.10	-	-
25. Scenadesmus	5 ±14.87	29 ±34.09	8 ±12.02	14 ±18.55	9 ±15.05	-	-	-
26. Synedra	16 ±23.09	18 ±20.44	22 ±40.23	17 ±20.23	14 ±27.41	5 ±14.90	7 ±11.03	3 ± 8.45
27. Spirulina	72 ±34.65	24 ±44.09	25 ±23.87	16 ±34.20	57 ±33.02	16 ±20.81	18 ±20.39	20 ±28.34
28. Spirogyra	52 ±42.09	62 ± 50.20	63 ±50.33	42 ±12.92	16 ±10.32	11 ±20.11	- ±12.20	4 ±19.43
29. Scenedesmus	16 ±20.28	-	-	-	-	-	-	-
30. Trachilomonas	4 ±12.32	11 ±20.11	2 ±8.56	5 ±10.21	21 ±34.65	3 ±10.00	-	-
31. Volvox	24 ±13.23	14 ±10.22	11 ±34.21	-	19 ±22.13	4 ±20.54	3 ±9.34	-
32. Zygnema	24 ±12.32	26 ±34.98	37 ±20.12	48 ±30.87	16 ±10.23	16 ±8.90	15 ±12.34	8 ±12.39
Un-identified	11	7	2	-	4	2	-	-
b) ZOOPLANKTON								
1. Asplanchna	10 ±8.90	13 ±21.23	8 ±8.85	7 ±10.34	11 ±12.34	-	-	-
2. Brachionus	9 ±10.19	9 ±20.23	14 ±13.22	12 ±14.23	14 ±16.30	2 ±12.12	-	-
3. Bosmina	15 ±12.01	3 ±10.13	5 ±12.35	2 ±10.23	-	4 ±12.22	2 ±11.25	-
4. Canthocamptus	7 ±9.12	12 ±22.32	14 ±12.02	-	-	-	-	-
5. Cyclops	14 ±20.11	17 ±13.32	15 ±33.28	21 ±12.20	16 ±18.24	2 ±20.22	3 ±11.19	-
6. Daphnia	4 ±16.34	3 ±8.29	5 ±6.33	9 ±12.12	16 ±11.25	-	4 ±10.10	-
7. Diaptomus	9 ±7.88	5 ±10.92	8 ±13.65	4 ±15.62	2 ±9.78	-	-	-
8. Filinia	14 ±20.70	15 ±23.54	17 ±22.19	9 ±14.03	20 ±14.93	2 ±10.34	2 ±8.99	4 ±9.88
10. Moina	5 ±12.90	11 ±11.05	14 ±19.00	3 ±10.89	-	-	-	-
11. Mytilina	9 ±6.75	8 ±10.64	8 ±12.33	10 ±12.23	11 ±13.65	3 ±14.03	4 ±11.35	7 ±10.23
12. Keratella	10 ±10.33	12 ±14.21	12 ±20.34	8 ±9.99	10 ±12.54	5 ±13.84	2 ±11.22	6 ±12.53
13. Polyarthra	13 ±20.04	10 ±11.42	24 ±16.43	-	8 ±12.26	-	-	-
14. Monnstyla	5 ±10.23	7 ±9.34	14 ±20.33	9 ±12.76	-	3 ±10.34	4 ±11.37	5 ±10.02
Un-identified	2	2	-	2	3	-	2	-

APPENDIX TABLE: 6 Second year data planktonic productivity (individuals per litre of water) from the river Ravi strectch from Baloki headworks to Sidhnai barrage (Second Year).

	RIVER SITE SAMPLING STATIONS					EFFLUENT DISCHARGING TRIBUTARIES		
	R1	R2	R3	R4	R5	T1	T2	T3
a) PHYTOPLANKTON								
1. Aphanothece	110 ±180.09	167 ±105.87	105 ±99.34	40 ±42.83	190 ±129.00	12 ±22.43	13 ±26.91	8 ±29.00
2. Anabaena	28 ±66.90	45 ±39.99	101 ±65.23	65 ±101.45	39 ±30.56	9 ±27.23	22 ±44.44	16 ±25.23
3. Aphanocapsa	122 ±160.00	167 ±98.56	47 ±43.21	22 ±45.92	11 ±50.22	-	-	-
4. Arthrospira	2 ±16.45	11 ±34.98	3 ±14.32	-	11 ±26.22	-	3 ±18.20	3 ±11.43
5. Bumilleria	66 ±45.86	45 ±39.04	78 ±51.32	100 ±95.80	32 ±33.29	14 ±44.09	-	-
6. Bacillaria	22 ±45.09	8 ±28.23	3 ±17.00	22 ±45.09	26 ±44.21	-	-	-
7. Cladophora	11 ±41.00	6 ±28.03	-	-	-	-	-	-
8. Closterium	3 ±28.80	5 ±42.10	8 ±24.24	-	2 ±16.00	-	-	-
9. Cyclotella	22 ±34.09	32 ±44.21	11 ±22.01	44 ±24.11	2 ±25.98	6 ±30.91	12 ±15.15	21 ±20.91
10. Cocconeis	5 ±26.00	13 ±38.22	10 ±20.92	15 ±19.32	8 ±20.88	-	-	-
11. Cosmarium	8 ±16.29	4 ±28.65	3 ±12.54	-	-	-	-	-
12. Denticulla	22 ±56.22	12 ±25.29	30 ±33.92	88 ±67.23	52 ±54.20	27 ±22.10	21 ±40.21	-
13. Dinobryon	10 ±16.55	6 ±25.10	-	-	-	8 ±29.13	9 ±28.28	18 ±23.44
14. Eudorina	10 ±23.00	22 ±40.00	29 ±22.80	20 ±30.24	40 ±22.90	-	-	-
15. Euglena	11 ±33.90	20 ±22.97	9 ±20.10	10 ±32.16	9 ±33.29	8 ±18.00	13 ±22.23	16 ±19.04
16. Melosira	38 ±44.00	26 ±34.48	40 ±26.98	44 ±28.94	30 ±22.93	11 ±23.03	3 ±16.00	-
17. Microcystis	40 ±81.00	26 ±26.90	23 ±54.24	57 ±40.01	14 ±34.56	-	-	-
18. Navicula	43 ±66.09	22 ±24.24	21 ±70.00	25 ±28.99	34 ±24.82	12 ±19.26	6 ±22.01	3 ±18.45
19. Oscillatoria	-	8 ±25.23	11 ±29.16	5 ±28.28	-	-	-	-
20. Pandorina	28 ±38.26	18 ±28.10	25 ±29.34	11 ±22.54	-	-	-	-
21. Peridinium	-	-	-	-		11 ±25.18	8 ±34.94	10 ±26.19
22. Phacus	11 ±19.34	8 ±25.25	4 ±16.45	6 ±28.32	4 ±19.56	4 ±16.34	3 ±26.90	-
23. Scenadesmus	10 ±10.44	15 ±27.71	2 ±26.00	9 ±20.04	12 ±18.30	-	-	-

Continued ....

Continued Table 6

	RIVER SITE SAMPLING STATIONS					EFFLUENT DISCHARGING TRIBUTARIES		
	R1	R2	R3	R4	R5	T1	T2	T3
24. <u>Synedra</u>	20 ±38.09	10 ±21.45	14 ±26.43	27 ±28.92	11 ±21.88	2 ±20.18	8 ±20.33	9 ±16.84
25.. <u>Spirogyra</u>	88 ±42.09	56 ± 50.20	87 ±50.33	64 ±12.92	21 ±10.32	- ±20.11	- ±12.20	- ±19.43
26. <u>Trachilomonas</u>	11 ±22.10	-	6 ±16.60	9 ±20.00	11 ±30.90	8 ±12.12	2 ±10.15	-
27. <u>Volvox</u>	29 ±33.95	18 ±26.34	18 ±41.40	9 ±26.80	13 ±30.08	7 ±29.40	-	-
28. <u>Zygnema</u>	45 ±23.80	20 ±56.09	58 ±22.98	26 ±56.23	10 ±20.90	9 ±18.34	5 ±16.77	-
Un-identified	18	11	6	3	4	5	2	4
b) ZOOPLANKTON								
1. <u>Asplanchna</u>	9 ±20.45	10 ±16.89	6 ±11.40	11 ±16.05	6 ±19.10	-	-	-
2.. <u>Brachionus</u>	10 ±20.11	7 ±16.25	8 ±12.45	14 ±13.00	12 ±24.24	-	-	-
3. <u>Bosmina</u>	10 ±22.93	5 ±19.45	6 ±18.00	-	-	3 ±11.10	5 ±12.22	2 ±13.38
4. <u>Canthocamptus</u>	10 ±11.38	8 ±28.09	10 ±22.03	12 ±20.40	3 ±12.04	-	-	-
5. <u>Cyclops</u>	10 ±33.09	11 ±22.20	8 ±35.03	4 ±18.80	10 ±29.22	-	-	-
6. <u>Daphnia</u>	3 ±20.90	5 ±14.22	4 ±11.20	8 ±10.19	7 ±20.00	3 ±14.25	2 ±8.16	-
7. <u>Diaptomus</u>	7 ±18.80	3 ±13.44	8 ±10.00	5 ±16.60	3 ±12.20	-	-	-
8. <u>Filinia</u>	-	15 ±20.40	20 ±25.00	10 ±18.18	11 ±20.20	3 ±16.80	4 ±10.22	2 ±14.38
9. <u>Moina</u>	3 ±22.00	7 ±16.62	5 ±18.24	-	-	-	-	-
10. <u>Keratella</u>	12 ±18.24	9 ±15.60	7 ±14.00	6 ±12.40	8 ±11.02	2 ±14.23	5 ±18.00	4 ±28.00
11. <u>Polyarthra</u>	15 ±20.09	11 ±16.26	18 ±20.00	6 ±16.80	5 ±10.10	-	-	-
12. <u>Monnstyla</u>	6 ±16.90	10 ±12.08	10 ±16.22	7 ±11.65	2 ±12.80	5 ±12.28	7 ±10.00	4 ±18.98
Un-identified	3	1	4	4	3	3	1	2