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Effect of Industrial Effluents from Iron and Steel Company on Benthic Macroinvertebrate Communities of Fresh Water Ponds in India

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Abstract:
At present, most of the water bodies including ponds have been seriously polluted by several industrial effluents. Benthic macroinvertebrates which are the main faunal component and play an important role in nutrient recycling and flowing of energy in aquatic ecosystem and are primarily affected by the polluted industrial effluents. Here, we have investigated the effect of industrial effluent discharges on water quality and biodiversity of benthic macroinvertebrates in fresh water ponds in West Bengal, India. Principal Component Analysis reveals that the four industrial effluent reach ponds contains higher values of physico-chemical parameters such as Hardness, Fluoride, Cyanide, Free carbon dioxide, Total suspended solid, Inorganic nitrogen, Phosphate, Hydrogen sulphide, Mercury and lower values of Dissolve Oxygen & Primary Productivity than one controlled pond. Pollution sensitive groups (e.g., Ephemeroptera, some of Hemiptera and Arachnids) are associated to the controlled pond and more tolerant groups (e.g., Chironomidae, Culicidae, Syriphidae) have greater abundance in the polluted ponds. Canonical Correspondence Analysis indicates that such phico-chemical parameters have higher influence in the distribution and abundance of macroinvertebrates. The percentage of functional feeding groups like Collector- Gatherers and Collector – Filters are high and biodiversity indices are low in industrially effluent reach ponds.

Keywords: *Benthic macroinvertebrates, physico-chemical parameters, industrial effluent, biodiversity, freshwater pond*

1. Introduction

One of the most critical problems of developing countries is improper management of vast amount of wastes generated by various industrial activities. More challenging is the unsafe disposal of these wastes into the ambient environment. Water bodies especially freshwater reservoirs and ponds are the most affected because they do not have self cleaning ability and therefore readily accumulate pollutants. This has often rendered these natural resources unsuitable for both primary and/or secondary usage. During the past few decades Indian industries have registered a quantum jump, which has contributed to high economic growth but simultaneously it has also given rise to severe environmental pollution. Consequently, the water quality is seriously affected which is far lower in comparison to the international standards. Industrial waste water usually contains specific and readily identifiable chemical compounds. It is found that one-third of the total water pollution comes in the form of effluent discharge, solid wastes and other hazardous wastes. Sponge iron industries are one of the major industries in India and also potential sources of contaminants in natural water sources due to its manufacturing and processing nature; the effluents are either directly discharged to adjoining land areas or inland lakes or river. Some of the major contaminants in effluent streams are heavy metals viz. Fe, Cr, Cd and Pb, toxic chemicals like oil and grease, cyanide (CN^-) etc., which produce cumulative toxic effects over time, leads to an alteration in physico-chemical properties of water and sediment including aquatic organisms (Giorgi and Malacalza, 2002). Benthic macroinvertebrates inhabit river beds, lakes and reservoirs and are associated with various types of substrates such as mineral sediments, detritus, macrophytes and filamentous algae (Rosenberg and Resh, 1993). They are essential elements in lentic and lotic trophic webs, participating in the energy flow and nutrient cycling. They are also important food resources for fish and some insectivorous birds. The distribution of aquatic organisms is the result of interactions among their ecological role, the physical conditions that characterize the habitat, and food availability (Merritt and Cummins, 1984). Because they reflect environmental changes, benthic macroinvertebrates are often used as indicators of the effects of human activity on water system and provide information on habitat and water quality (Woodcock and Huryn, 2007). Until now bioassessment based on benthic macroinvertebrates exist upon flowing waters (Barbour et al. 1999) and standing waters (Rossaro et al. 2007), and for broad wetland areas in Australia and North America (Hicks and Nedeau, 2000; Apfelbeck, 2001;). But there are still few macroinvertebrate based methods proposed for assessing ecological quality of small lentic bodies in Europe (Biggs et al. 2000; Solimini et al. 2008; Trigal et al. 2009). Therefore, it has a poor knowledge about the sensitivities of ponds benthic macroinvertebrates to anthropogenic stressors. Although in some earlier studies it was seen that some environmental and physical

factors (pH, depth, dissolve oxygen, macrophyte, turbidity and pond size) can influence the species composition of pond communities (Nicolet et al. 2004; Della Bella et al. 2005; Jeffries, 2005) but relatively few established works were done about human influence on benthic macroivertebrates in fresh water ponds (Della Bella and Mancini, 2009). Della Bella and Mancini (2009) investigate the effect of human impact (water pollution or habitat alteration) on macroinvertebrates and diatoms communities in Italian coastal permanent ponds. Particularly in India, most of the studies on ponds benthic macroinvertebrates were based on their community structure and seasonal variation (Sinha and Roy, 1991; Khan and Ghosh, 2001; Saha et al. 2007; Jana et al. 2009). Best of my knowledge, only Chakravorty et al. (2014) done a few works of the impact of industrial effluent on benthic communities in fresh water ponds.
The main purpose of this study is to carry out an analysis of physico-chemical parameters, identification of benthic macroinvertebrates to species composition, distribution, abundance and trophic structure of different species in the industrially polluted fresh water ponds near an iron and steel company in Midnapore district of West Bengal, India. In combination with this, the study also analyses the environmental variables that influence the community composition in the industrially polluted pond.

2. Materials and Method

The study area is located in Kharagpur, an industrial town in Paschim Medinipur district of West Bengal, India. The town lies 22.33°N, 87.32°E and has an average elevation of 29 m (95 ft). The annual mean temperature in this town is ranging from 22−30 °C and average annual rainfall is around 1140 mm. Gokulpur, located in the town of Kharagpur, is the main industrial centre and major industries present here are sponge iron industries. Untreated industrial effluent from these industries is gushing out from the boundary wall and freely flowing on to the adjoining fields and then entered into the adjacent water bodies and polluted all of them.
For studying the impact of industrial effluent discharge on fresh water five ponds were selected. Among them four ponds (Pond P1, Pond P2, Pond P3, and Pond P4) were selected in Gokulpur in relation to horizontal proximity of industrial effluent discharge point (100 m, 300 m, 750 m, 1150 m) and one pond was selected for reference (Pond C) and it was far away (about 10 km) from this industrial area. The industrial effluent directly entered into Pond P1 but in other ponds (P2, P3, and P4) it entered through rain water. The reference pond is surrounded by forested area in all sides and very few macrophytes are present in this pond. The names of these macrophytes are Limnophila indica Linn, Colocasia esculenta Schott, Enhydra fluctuans Loureiro and Polygonum barbatum Linn. The other four ponds (Pond P1, Pond P2, Pond P3, and Pond P4) are surrounded by grass field and bushy area and are infested with many aquatic macrophytes. Main macrophytes of these ponds are Eichhornia crassipes Marcius, Lemma aquinoctialis Welwitsch, Sagittaria montevidensis Chamissoet Sc., Monochoria hastate Linn, Colocasia esculenta (L) Schott, Typha domingensis Persoons, Spirodella polyriza Linn and Polygonum hydropiper Linn. The wide spread distribution and luxuriant growth of these aquatic macrophytes in the fresh water ponds was reported as an indication of pollution (Uwadiae, 2010). Brief descriptions of the ponds used for this investigation are presented in Table 1.
Benthic macroinvertebrates were collected in every month from February 2012 to August 2012 in between the time period 7am − 8am. At each sampling site three substrate sub sampling were taken by using D-frame dip net (mesh opening 500 μm) from the four corners of the ponds. The collected samples were sorted and stored in 70% ethyl alcohol in samples-bottles. Identifications of benthic macroinvertebrates were done by using taxonomic keys, following the methods of Pennak (1978), Bal and Basu (1994). Identifications of species were confirmed by the Central Entomological Laboratory of Zoological Survey of India, Kolkata, India. Benthic macroinvertebrates were assigned to a trophic category (functional feeding group) based on Merrit and Cummins (1994) and Mandaville (2002). Water and soil samples were also collected in every month from February 2012 to August 2012 in three replicates from four corners of each pond and mean values were taken into the consideration. Apart from this, the industrial effluents from metal refinery were also collected for physico-chemical analysis. These samples were kept in cooling system in our laboratory. Physico-chemical parameters like water temperature and pH were measured instantly at the study site. Other physico-chemical parameters (dissolve oxygen, primary productivity, biological oxygen demand, free carbon dioxide, salinity, hardness, organic carbon, inorganic nitrogen, phosphorus as phosphate, total suspended solid, fluoride) and toxic substances (hydrogen sulphide, sulphate, cyanide, heavy metals like mercury, lead, cadmium) were analyzed by using standard methods within 48 h of collection of samples (APHA 2005; Trivedy and Goel, 1984).
Species richness and faunal diversity of benthic macroinvertebrates were calculated by Margalef's Index, Simpson's index of diversity and Shannon Wiener Index. One-way ANOVA (analysis of variance) was used to find out the significant differences of the physico-chemical parameters between five ponds. All the calculations of diversity indices, ANOVA and canonical correspondence analysis (CCA) were made by PAST software.

3. Results

3.1. Water Quality Condition

The result of physico-chemical parameters of industrial effluent, water samples measured at five study sites and F- values of ANOVA were presented in Table 2. The effluent was compared against the ISI standard for surface water bodies. As the effluent released by the sponge iron industries it contains higher amount of pH, hardness, total suspended solid, nitrate, phosphate, hydrogen sulphide, sulphate and heavy metals like mercury, lead, cadmium and cyanide. Some marked variations in the physico-chemical parameters were observed between five ponds study sites. It was observed from analysis of variance (ANOVA) that among all physico-chemical parameters such as: Dissolved Oxygen, Primary productivity, Biological Oxygen Demand, Free carbon dioxide, Hardness, Phosphate, Total suspended solid, Fluoride, Hydrogen sulphide, Sulphate, Mercury and Lead were significantly different ($P<0.05$) among the study sites. The values of Dissolved Oxygen and Primary productivity were higher in Pond C and lower values found in Pond P1 and Pond P2 while the values of other physico-chemical parameters (Biological Oxygen Demand, Free carbon dioxide, Hardness, Phosphate, Total suspended solid, Fluoride, Hydrogen sulphide, Sulphate, Mercury and Lead) were higher in Pond P1 and Pond P2, lower in Pond C and intermediate values in Pond P3 and Pond P4.

Separation of five ponds on the basis of physico-chemical parameters were clearly seen in PCA (Fig. 1). The first two axis 1 and axis 2 of PCA explained by 87.89% and 6.45% of variance, respectively. The most important variables in axis 1 were Hardness, Fluoride, Cyanide, Free carbon dioxide, Total suspended solid, Inorganic nitrogen and Phosphate. In axis 2 most important variables were Hydrogen sulphide and Mercury. PCA also explained Dissolve Oxygen and Primary Productivity which were higher in Pond C negatively correlated with other environmental variables. According to PCA Pond P1 and Pond P2 differ from Pond C by the higher amount of Hardness, Fluoride, Cyanide, Free carbon dioxide, Total suspended solid, Inorganic nitrogen, Phosphate, Hydrogen sulphide, Mercury and lower value of Dissolve Oxygen and Primary Productivity. Pond P3 and Pond P4 had intermediate values of these variables.

3.2. Faunal Composition, Abundance and Distribution

The species composition, distribution, abundance and functional feeding group [FFG] of benthic macroinvertebrates at five ponds study sites were presented in Table 3. Pond C had highest number of species followed by Pond P4 while Pond P1 recorded the lowest number of species diversity. Wide fluctuations were observed in the abundance of taxa from pond to pond. Pond C had greater representation of Ephemeroptera (16.62%) followed by Pond P4 (2.66%) and Pond P3 (1.21%) where as no Ephemeroptera was recorded in Pond P1 and Pond P2. Among Ephemeroptera Cloeon sp. (Family Baetidae) recorded only in Pond C. Hemiptera represent 10 species of which Micronecta scuttellaris scuttellaris (Family Corixidae) and Nychia marshalli (Family Notonectidae) were only present in Pond C. Other Hemiptera like Corixa sp. (Family Corixidae), Ranatra gracilis Dalas (Family Nepidae) Anisops sp. (Family Notonectidae) and Paraplea sp (Family Pleidae) were found in all study ponds but their abundance were higher in Pond P1 and Pond P2 and lower abundance found in Pond C. Diplonychus rusticus (Family Belostomidae) were found in all study ponds but absent in pond C. Coleoptera only represent in pond C but in other ponds they were absent except Canthydrus luctuosus, Laccophilus parvulus parvulus and Berosus fairmairei Zaitz. The above three species were also found in Pond P4. Odonata represent five species of which Urothermis signata and Pseudagrion sp.found only in Pond C. Diptera formed a major component of fauna in this study. The abundance of Chironomus sp. (Family Chironomidae) was high in Pond P1 (32.49%) and Pond P2 (32.19%) and low in Pond C (2.98%). The other taxa like Molluscs, Annelids, crustacean and Arachnids were present in pond C but absent in all ponds.

Diversity indices calculated for five study sites were summarized in Table 4. Margalef's species richness index (d) was highest in Pond C, followed by Pond P4; it was lowest in the Pond P1. The species diversity measured by the Shannon Diversity indices and Simpson's index of diversity and both were highest in Pond C, followed by Pond P4; Pond P1 had the lowest diversity.

The percentages of functional feeding groups of benthic macroinvertebrates in five ponds were calculated in Table 4. From this table it was observed that percentages of Collector –Gatherers and Collector –Filters were high in all the ponds except in Pond C. It was also observed that scraper and shredder were present in Pond C but absent in other ponds. Only Pond P4 had very low percentage of scrapers.

Most important environmental variables in PCA (Hardness, Fluoride, Cyanide, Free carbon dioxide, Total suspended solid, Inorganic nitrogen and Phosphate in axis 1 and Hydrogen sulphide and Mercury in axis 2) were also used in CCA (Fig. 2) to explain the relationship between benthic macroinvertebrates and their environmental variables. The first two axis of CCA explained 93.78% and 4.81% of the variance in benthic communities. According to CCA Ephemeroptera, Coleoptera, most of the Hemiptera, Odonata , Molluscs, Crustacea, Annelida and Arachnida were abundant in ponds with higher concentration of dissolve oxygen and primary productivity. In contrast most of the Diptera (Chironomous sp., Culex sp., Chrysogaster sp), Hemiptera (Diplonychus rusticus, Corixa sp., Paraplea sp.), Odonata (Enallagma sp., Ischnura sp.) occurred in ponds with higher values of Hardness, Fluoride, Cyanide, Free carbon dioxide, Total suspended solid, Inorganic nitrogen, Phosphate, Hydrogen sulphide and Mercury.

4. Discussion

The separation of four ponds (Pond P1, PondP2, Pond P3, Pond P4) from pond C in PCA was due to higher values of Hardness, Fluoride, Cyanide, Free carbon dioxide, Total suspended solid, Inorganic nitrogen, Phosphate, Hydrogen sulphide, Mercury and lower value of Dissolve Oxygen and Primary Productivity. This difference of environmental variables were expected because industrial effluent directly reach to Pond P1 and in other three ponds (P2, P3, P4) this effluent reaches only by rain water. As the Pond C situated far away from this industrial area the water of this pond is clearer than other ponds.

Higher values of hardness and fluoride in pond water indicate inorganic pollution probably originated from industrial effluent (Subrahmanyam and Yadaiah, 2001). Hardness is a measurement of the amount of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water. Animals and plants require calcium and magnesium for life. Calcium is an important component of cell walls, shells and bones of many aquatic organisms. Magnesium is a component of chlorophyll, which is necessary for photosynthesis in green plants. Water is considered hard if the ion concentration exceeds 150 mg/L (Baird and Cann, 2005). Most fish and aquatic organisms live in waters with hardness between 15 and 200 mg/L.

Fluoride is essential in minute quantity for normal mineralization of bone and teeth (for formation of dental enamel). Fluoride stimulates growth of many plant species but on other hand when fluoride is taken up in excessive amount may prove toxic to plants and other aquatic animals.

Similarly high values of cyanide in pond water also indicate pollution. The cyanide ion (CN^-) is the predominant stable form of free cyanide above a pH of about 9.2. As the pH drops down, increasing amounts of CN^- converts to hydrogen cyanide (HCN). The percentage of HCN continues to increase as the pH drops until at a pH of 7.0 and about 99.5 percent of the cyanide exists as HCN at this level of pH. This HCN forms are highly toxic to human and aquatic life if ingested (Moran, 1998).

Total suspended solids define as solids in water that can be trapped by a filter. They can include a wide variety of material, such as silt, decaying parts of plant and animal matters, industrial wastes and sewage. Total suspended solids are very useful parameter describing the Chemical constituents of the water. High value of total suspended solids in pond water indicates pollution by industrial effluent (Abhishek *et al.* 2006). It is known that higher suspended solid decreases the rate of photosynthesis by reducing penetration of light and temperature (Van Nieuwenhuyse and LaPerriere, 1986; Lloyd *et al.* 1987). Benthic macroinvertebrates are also greatly affected by suspended solid. It damage exposed respiratory organs of benthic macroinvertebrates and causing their dislodgment (Langer, 1980).

All organisms require nitrogen for the basic process of life to synthesize protein required for growth and reproduction. Phosphorus is a nutrient for plant growth and a fundamental element in the metabolic reaction of plants and animals. It controls algal growth and primary productivity. High level of inorganic nitrogen and phosphorus in pond water indicate industrial pollution which leads to eutrophication (Abhishek *et al.* 2006 and Sahni and Yadav, 2012).

Hydrogen sulphide is a common but toxic metabolite formed in a fresh water pond. When aerobic bacteria breaks down excess feed and accumulated organic waste then oxygen is depleted, and create anaerobic zone where sulphate reducing bacteria will thrive, resulting in the build up of hydrogen sulphide. Excess amount of hydrogen sulphide in fresh water can also be produced either by the decomposition of organic effluents from municipal sewage and industrial sewage (Colby and Smith, 1967) or released directly from industrial effluents. According to USEPA (2005) continuous exposure of hydrogen sulphide causes mortality of aquatic animals.

Dissolve oxygen is considered one of the most important limnological variables, both for the characterization of aquatic ecosystems and for the maintenance of aquatic life. Many organisms, specially the indicators of good environmental quality require high concentrations of dissolve oxygen for their survival (Bispo *et al.* 2006) This situation was observed in this study, with a positive relationship between Ephemeroptera, Coleoptera, most of the Hemiptera, Odonata , Molluscs, Crustacea, Annelida and Arachnida and oxygen concentration. Thus, according to these variables, the ponds studied appear to differ in their status of environmental quality, with Pond C showing better water quality. Pond P1 and Pond P2 are very impacted and Pond P3 and Pond P4 are in an intermediate environmental situation.

This trend is confirmed by the Correspondence Analysis, when we compare the species diversity, faunal composition and abundance in five ponds. The number of macro invertebrate species was significantly higher in reference pond (Pond C) than both intermediate (Pond P3 and Pond P4) and heavily degraded (Pond P1 and Pond P2) ponds. According to Ogbeibu and Egborge (1995) high species diversity is expected in ecosystems devoid of significant anthropogenic impacts. Lower species diversity of benthic macroinvertebrates was also reported by Cieminski and Flake (1995) in waste water ponds in southern Idaho. In Pond C the abundance of Ephemeroptera, Coleoptera, most of the Hemiptera, Odonata , Molluscs, Crustacea, Annelida and Arachnida was high, while Pond P1 and Pond P2 had highest abundance of Diptera (*Chironomus* sp, *Culex* sp and *Chrysogaster* sp). Pond P3 and Pond P4 were intermediate between Pond C and Pond P1 and Pond P2. In pond water Ephemeroptera comprise a group of organisms highly sensitive to pollution, requiring clean and well oxygenated waters for their survival (Menetrey *et al.* 2008). Thus the occurrence of these taxa is an indication of good water quality. This environmental integrity is also indicated by some species of Hemiptera which include *Micronecta scuttellaris scuttellaris* is a group extremely sensitive to pollution and live in well oxygenated water (Rueda *et al.* 2002). In pond water Hydrachna sp. (Acarina) is also very sensitive to pollution and was not usually found in ecosystems altered for water abstraction (Gerecke and Lehmann, 2005).

In contrast, the presence of Chironomus sp, *Culex* sp and *Chrysogaster* sp in Pond P1 and Pond P2 indicate water of poor quality. It is known that *Chironomus* sp are very tolerant to impacted and eutrophic environments. These organisms survive in the very negligible amount of dissolved oxygen and high nutrient tolerant organisms. Because Chironomidae larvae, have enhanced oxygen uptake and storage, due to the presence of hemoglobin-like molecules. Therefore, they may be better able to withstand in low dissolve oxygen.

Shifts in trophic structure (Monakov, 2003) are often indicative of a community responding to an overabundance of a particular food source, or to disturbance (Voshell, 2002). In all four ponds (Pond P1, Pond P2, Pond P3 Pond P4) higher percentage of Collector–Gatherers and Collector–Filters, absence of Scraper and Shredder indicate this disturbance. Similar observation was reported by CWAM (2007) in polluted water ecosystem. Scrapers tend to increase with an increase in the abundance of diatoms and decrease as filamentous algae (indicative of organic and nutrient enrichment) increases (King, 1993). Taxa in this functional feeding group tend to be relatively intolerant to stressors such as higher level of suspended solids that reduce their feeding areas (Yule *et al.* 2010). Shredder also disappears in the areas where suspended solids were higher (Yule *et al.* 2010). In the present study higher level of suspended solids in all the four ponds may cause reduction or absence of these feeding groups. Collector-Gatherers are the most abundant macroinvertebrates in many aquatic ecosystems; they feed on fine particulate organic matter that accumulates on the substrate and are responsible for the processing and re-suspension of those particles (Wallace and Webster, 1996). In all four ponds except in Pond C levels of nutrients (nitrogen, phosphorus) were sufficiently high to be considered eutrophic, favouring higher bacterial biomass and/or production (Weyers and Suberkropp, 1996). Therefore, enhancing food resources for Collector-Gatherers that can obtained nutrients from bacteria while feeding on fine particulate organic matter (Fisher and Gray, 1983). According to Uwadiae (2010), Collector-Filters were abundant in most of the sites where availability of suspended organic matter increases.

Species diversity and species richness indices at the five ponds study sites were also appeared to' respond the water quality deterioration at industrially polluted ponds ie Pond P1, Pond P2, Pond P3 and Pond P4. Simpson Diversity Index values range is in between 0 and 1. The greater value of this index indicates higher diversity and undisturbed environment (Norris and Georges, 1993). Shannon-Wiener Diversity Index values range is in between 0 and 5 (Kocataş, 2003). Stable community has a high index value which indicates high water quality while unstable community has a low index value which indicates low water quality (Norris and Georges, 1993). The Margalef Diversity Index is a measure of species richness. The greater value of this index indicates higher diversity (Norris and Georges, 1993). According to above range, higher species richness and species diversity indices at Pond C were associated with unaffected or unpolluted conditions where as lower species richness and species diversity indices in industrially polluted ponds often signified environmental stress due to industrial effluent (Norris and Georges, 1993; Wilhm and Dorris, 1966).

5. Conclusions

This study adds information about the main effects arising from industrial effluent of an Iron and steel company on benthic communities of fresh water ponds in India. The data presented in this study indicate extreme modification of benthic community structure in fresh water ponds that directly affected by iron and steel company discharge. The principal agents of this modification are increasing values of Hardness, Fluoride, Cyanide, Free carbon dioxide, Total suspended solid, Inorganic nitrogen, Phosphate, Hydrogen sulphide, Mercury and lower value of Dissolve Oxygen and Primary Productivity. As benthic macroinvertebrates are important component in fresh water habitat, lower species diversity, absence of sensitive species and changing in trophic structure of benthic community in industrially effluent reach ponds may hamper total ecosystem of that ponds. This effluent discharges flowed into the ponds should be treated scientifically and entry of raw industrial effluent into the ponds should be prohibited and regulated. Otherwise, it is not so far when we will lose our pond biodiversity which are valuable resources of fresh water, in a Wetland ecosystem.

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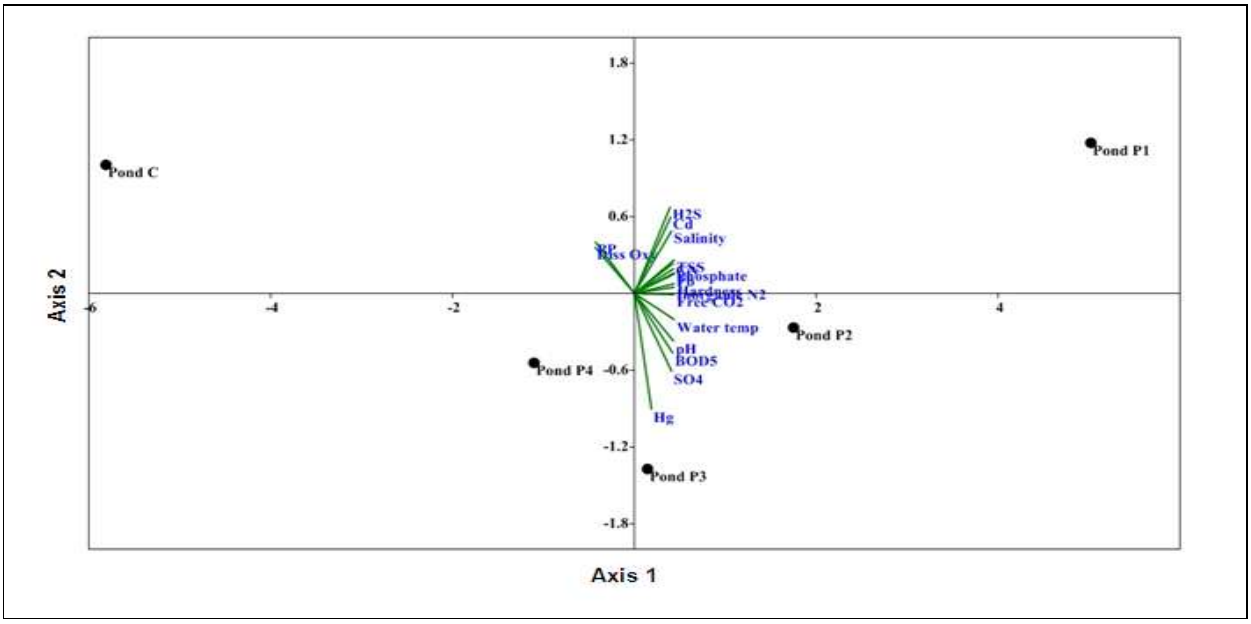

Figure 1

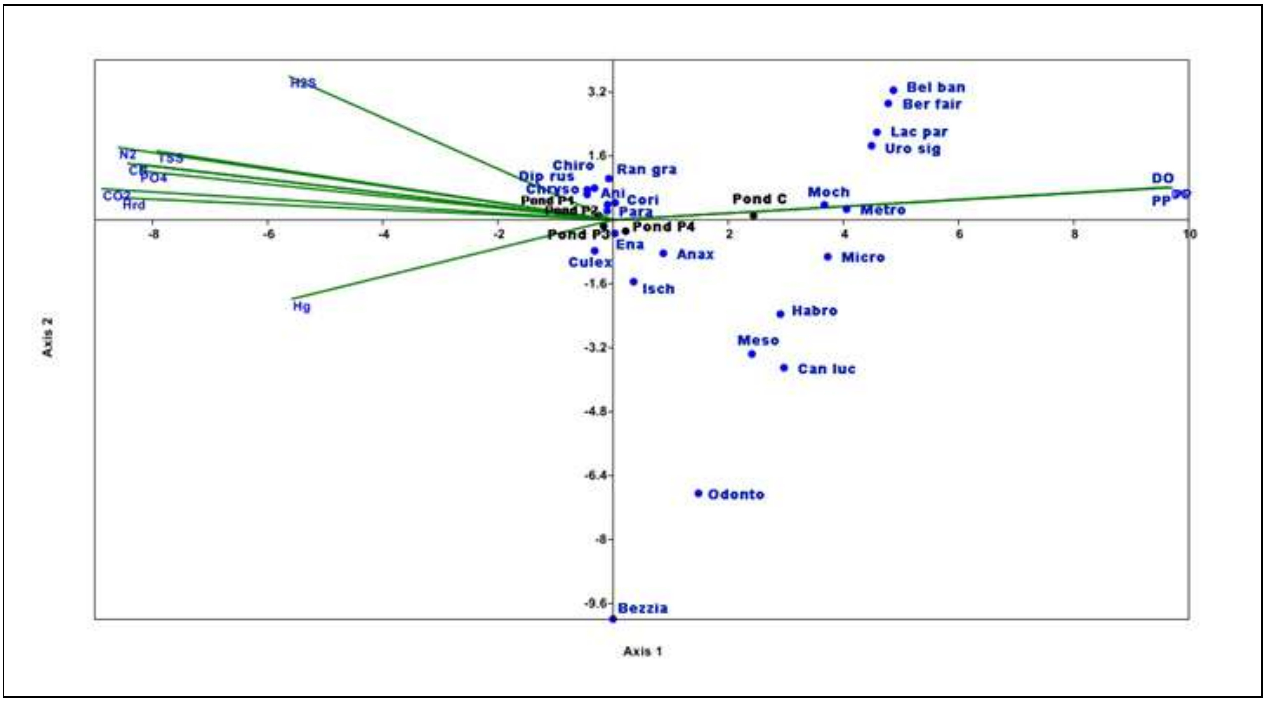

Figure 2

Figure Deatails:

Figure 1: Ordination diagram of the sampling sites by Principal Component Analysis (PCA), considering the physico-chemical parameters of water from controlled pond (Pond C) and polluted ponds (Pond P1, Pond P2, Pond P3 and Pond P4).

Figure 2: Canonical Correspondence Analysis (CCA) of faunal assemblages with environmental variables in five pond study sites. The Eigen-values of axis 1 and axis 2 were 0.421 and 0.022, respectively which explain 93.19% and 4.77% species. The aquatic insect species abbreviated as: Habro sp -*Habrophlebia sp*, Para sp - *Paraplea sp.*, Ani sp - *Anisops sp.*, Cori sp - *Corixa sp.*, Dip rus - *Diplonychus rusticus*, Metro sp - *Metrocoris sp*, Ran gra - *Ranatra gracilis Dalas*, Meso sp - *Mesovelia sp.*, Micro sp. - *Microvelia sp.*, Anax sp - *Anax sp.*, Uro sig - *Urothermis signata*, Ischnura sp - *Ischnura sp.*, Ena sp - *Enallagma sp.*, Bel ben - *Bellamya bengalensis*, Can luc - *Canthydrus luctuosus*, Lac par - *Laccophilus parvulus parvulus*, Bero fair - *Berosus fairmairei* Zaitz, Chiro sp - *Chironomous sp.*, Chryso sp - *Chrysogaster sp.*, Culex sp - *Culex sp.*, Odonto sp - *Odontomyia sp.*, Bezzia sp.- *Bezzia sp.*, Moch sp.- *Mochlonyx sp.* The environmental variables abbreviated as: DO - Dissolve oxygen, PP - Primary productivity, Free CO_2 – Free carbon dioxide, Inorganic N_2 - Inorganic nitrogen, PO_4 - Phosphorus as phosphate, TSS - Total suspended solid, H_2S - Hydrogen sulphide, CN - Cyanide, Hg – Mercury.

Study sites	Latitude	Longitude	Elevation	Area	Depth	Main aquatic vegetation
Pond C	22.25°N	87.17°E	23 m	12,141 m^2	5m	Limnophila indica , Colocasia esculenta , Enhydra fluctuans and Polygonum barbatum .
Pond P1	22.39°N	87.29°E	29 m	14,211 m^2	4m	Eichhornia crassipes , Lemma aquinoctialis , Sagittaria montevidensis, Monochoria hastate, Colocasia esculenta , Typha domingensis , Spirodella polyriza and Polygonum hydropiper .
Pond P2	22.39°N	87.28°E	29 m	13,450 m^2	4m	Eichhornia crassipes , Lemma aquinoctialis , Sagittaria montevidensis, Monochoria hastate.
Pond P3	22.39°N	87.29°E	29 m	12,200 m^2	3.5m	Eichhornia crassipes , Lemma aquinoctialis, Typha domingensis , Spirodella polyriza .
Pond P4	22.4°N	87.29°E	29 m	10,580 m^2	3m	Monochoria hastate, Colocasia esculenta , Typha domingensis , Spirodella polyriza and Polygonum hydropiper .

Table 1: Description of five study sites

Parameter	ISI Standard for surface water	Pond C	Pond P1	Pond P2	Pond P3	Pond P4	F values	Effluent
Water Temp (ºC)	-	24.3± 4.17	25.8± 4.8	25.5± 4.51	25.3± 3.22	25± 4.1	0.036	28.5 ± 4.65
pH	6.5-8.5	6.8 ± 0.27	8.5± 0.44	8.3 ± 0.27	8± 0.25	7.9±0.23	4.78	9.5 ±0.32
Dissolved Oxygen (mg/l)	4-6	5.52± 0.17	2.8± 0.19	3.2± 0.16	3.6 ± 0.14	3.8 ± 0.12	43.74*	1.7 ±0.38
Primary productivity (mgC/m^3/h)	-	915.6 ± 33.3	84.38 ±5.89	165.63 ± 10.8	312.5 ± 10.57	375.38 ± 12.5	349.91*	-
Biological Oxygen Demand (mg/l)	3	1.2 ± 0.8	10.16 ± 0.5	8.4 ± 0.5	8 ± 0.1	7.6 ± 0.7	35.76*	15.32 ± 4.26
Free carbon dioxide (mg/l)	6	4.4 ± 1.29	13 ±1.51	11 ± 1.41	8.8 ± 1.1	8.8 ± 1.15	6.06*	22.88 ± 4.79
Salinity (ppt)	-	0.06 ± 0.01	0.17 ± 0.04	0.1 ± 0.008	0.1 ± 0.008	0.08 ± 0.001	4.85	0.28 ± 0.085
Hardness (mg/l)	300	80.4 ± 20	1120 ± 145.49	712 ± 60.25	608 ± 43.08	552 ± 73.2	21.36*	1300 ± 387.9
Inorganic nitrogen (mg/l)	20	0.86 ± 0.075	5.84 ± 1.46	5.11 ± 0.96	3.22 ± 0.55	3.14 ± 0.63	5.04	23.72 ± 5.35
Phosphate (mg/l)	-	0.11± 0.025	2.9 ±0.58	2.1 ± 0.46	1.18 ±0.28	1.5 ±0.09	8.54*	5.26 ± 1.18
Total suspended solid (mg/l)	-	34 ± 6.07	2151 ± 417.9	1271 ± 272.1	917 ± 176.7	806 ± 88.04	10.29*	3200 ± 721.3
Fluoride (mg/l)	1.5	0.46 ± 0.02	5.8 ±1.25	3.7 ± 0.82	3 ±0.64	2.5 ±0.44	6.6*	8.2 ± 2.32
Hydrogen sulphide (mg/l)	-	-	124.1 ±5.32	40.71 ± 3.4	31.45 ±0.98	10.4 ± 0.27	243.82*	165 ±30.25
Sulphate (mg/l)	400	26.30 ± 2.59	630 ± 102.22	590 ± 135.13	540 ± 85.24	480 ± 63.45	7.51*	1045 ±363.30
Mercury (mg/l)	0.001	-	0.02 ± 0.008	0.012 ± 0.01	0.045 ± 0.01	0.003 ± 0.00	7*	0.42 ± 0.09
Lead (mg/l)	0.1	-	2.8 ± 0.32	1.1 ± 0.29	0.9 ± 0.27	0.45 ± 0.30	12.1*	5.4 ±0.45
Cadmium (mg/l)	0.01	-	0.15 ± 0.04	0.08 ±0.01	0.05 ±0.03	0.01 ± 0.009	2.26	0.92 ±0.29
Cyanide (mg/l)	0.05	-	0.24 ± 0.05	0.15 ± 0.002	0.14 ±0.034	0.08 ±0.005	4.8	0.32 ± 0.12

Table 2: Mean values and standard deviation of physico-chemical parameters of industrial effluent and water samples measured at five study sites

Phylum/ Class/Order	Family	Genus and Species [FFG]	Pond C	Pond P1	Pond P2	Pond P3	Pond P4
Ephemeroptera (Order)	Leptophlebiidae	*Habrophlebia sp.* [C-G]	15 (3.72)	-	-	5 (1.21)	9 (2.66)
	Baetidae	*Cloeon sp.* [C-G]	52 (12.90)	-	-	-	-
Hemiptera (Order)	Belostomatidae	*Diplonychus rusticus* (Fabricius). [PRD]	-	20 (2.20)	13 (2.23)	8 (1.93)	4 (0.91)
	Corixidae	*Micronecta scuttellaris scuttellaris* (Stal) [PIER-H]	79 (19.60)	-	-	-	-
		Corixa sp. [PRD]	10 (2.48)	68 (7.49)	50 (8.56)	34 (8.21)	20 (5.92)
	Gerridae	*Metrocoris sp* .[PRD]	4 (0.99)	-		1 (0.24)	1 (0.29)
	Mesoveliidae	*Mesovelia sp.* [PRD]	10 (2.48)	-	-	6 (1.45)	7 (2.07)
	Nepidae	*Ranatra gracilis* Dalas. [PRD]	2 (0.49)	14 (1.54)	10 (1.71)	4 (0.97)	4 (0.91)
	Notonectidae	*Anisops sp.* [PRD]	15 (3.72)	70 (7.71)	55 (9.42)	35 (8.45)	23 (6.80)
		Nychia marshalli. [PRD]	20 (4.96)	-	-	-	-
	Pleidae	*Paraplea sp.* [PRD]	5 (1.24)	34 (3.74)	25 (4.28)	19 (4.59)	10 (2.96)
	Vellidae	*Microvelia sp.* [PRD]	26 (6.45)	-	-	-	14 (4.14)
Coleoptera (Order)	Noteridae	*Canthydrus laetabilis* (walker*)* [PRD]	7 (1.74)	-	-	-	-
		Canthydrus rifsemai (Regimbert) [PRD]	5 (1.24)	-	-	-	-
		Canthydrus luctuosus (Aube*)* [PRD]	2 (0.49)	-	-	-	2 (0.59)
	Dytiscidae	*Laccophilus parvulus parvulus* (Aube) [PRD]	9 (2.23)	-	-	-	2 (0.59)
		Hydrovatus sp. [PRD]	7 (1.74)	-	-	-	-
		Hydroglyphus flammulatus (Sharp*)* [PRD]	1 (0.25)	-	-	-	-
	Hydrophilidae		2 (0.49)	-	-	-	-
		Amphiops pedestris (Sharp) [PRD]	1 (0.25)	-	-	-	-
		Globaria sp.[SHR]	1 (0.25)	-	-	-	-
		Enochrus esuriens (Walker) [C-G]	4 (0.99)	-	-	-	-

		Paracymus evanescens (Sharp) [SHR]	2 (0.49)	-	-	-	-
		Hydrochus binodosus Mots. [SHR]	12 (2.98)	-	-	-	2 (0.59)
		Berosus fairmairei Zaitz [C-G]					
Odonata (Order)	Libellulidae	*Urothermis signata* [PRD]	4 (0.99)	-	-	-	1 (0.29)
	Aeshnidae		1 (0.25)	-	2 (0.34)	1 (0.24)	1 (0.29)
		Anax sp. [PRD]					
	Coenagrionidae		2 (0.49)	10 (1.1)	8 (1.37)	5 (1.21)	5 (1.48)
		Enallagma sp. [PRD]					
			5 (1.24)	-	-	-	-
		Pseudagrion sp. [PRD]					
			1 (0.25)	-	4 (0.68)	2 (0.48)	2(0.59)
		Ischnura sp. [PRD]					
Diptera (Order)	Chironomidae	*Chironomus sp.* [C-G]	12 (2.98)	295 (32.49)	188 (32.19)	95 (22.95)	73 (21.59)
	Ceratopogoni-dae	*Bezzia sp.* [PRD]	-	-	-	1 (0.24)	1 (0.29)
				-	-	1 (0.24)	2 (0.59)
	Stratiomyidae	*Odontomyia sp.* [C-G]	1 (0.25)				
				354 (38.99)	204 (34.93)	179 (43.24)	143 (42.31)
	Culicidae	*Culex sp.* [C-F]	8 (1.98)				
	Chaboridae	*Mochlonyx sp.* [PRD]	5 (1.24)	-	-	-	2 (0.59)
	Syriphidae	*Chrysogaster sp.* [C-G]	-	43 (4.74)	25 (4.28)	18 (4.35)	8 (2.37)
Molluscs (Phylum)	Viviparidae	*Bellamya bengalensis f.typica* (Lamarck) [SCR]	14 (3.47)	-	-	-	2 (0.59)
	Bithyniidae		5 (1.24)	-	-	-	-
	Thiaridae	*Gabbia orcula Frauenfeld* [SCR]	5 (1.24)	-	-	-	-
		Melanoides tuberculata (Mueller) [SCR]	3 (0.74)	-	-	-	-
	Bullinidae	*Terebia lineate* (Gray) [SCR]	2 (0.49)	-	-	-	-
	Lymnaeidae	*Indoplanorbis exustus* (Deshayes) [SCR]	2 (0.49)	-	-	-	-
		Lymnaea sp. [SCR]					
Annelids (Phylum)	Tubificidae	*Tubifex tubifex* [C-G]	5 (1.24)	-	-	-	-
Crustacea (Phylum)	Palaemonidae	*Macrobrachium sp.* [C-G]	4 (0.99)	-	-	-	-
	Candonidae		8 (1.98)	-	-	-	-
	Lynceidae	*Pseudocandona sp.* [C-F]	10 (2.48)	-	-	-	-
		Lynceus sp. [C-F]					
Arachnids (Class)	Hydrachnidae	*Hydrachna sp.* [PRD]	5 (1.24)	-	-	-	-
No of species			43	9	11	16	23
No of individuals			403	908	584	414	338

Table 3: Summary of the species composition, distribution, abundance and functional feeding group [FFG] of benthic macroinvertebrates at five study sites. (The values in parentheses represent percentage of abundance)

Metric	Pond C	Pond P1	Pond P2	Pond P3	Pond P4
No of Taxa	43	9	11	16	23
% of Ephemeroptera	16.62	-	-	1.21	2.66
% of Chironomidae	2.98	32.49	32.19	22.95	21.59
Simpson's Index of Diversity (1-D)	0.92	0.73	0.74	0.75	0.76
Shannon Wiener Index (log)	3.12	1.59	1.70	1.77	1.99
Margalef Richness Index	7.03	1.18	1.57	2.49	3.78
% Shredders	1.49	-	-	-	-
% Scrapers	7.69	-	-	-	0.59
% Filterers	6.45	38.99	34.93	43.24	42.31
% Gatherers	25.31	37.22	36.47	28.74	27.81
% Predators	36.72	23.79	28.59	28.02	29.29

Table 4: Variation of biodiversity metrics in five pond study sites