Efficiency of Pollution Tolerance Index (PTI) of macroinvertebrates in detecting aquatic pollution in an oxbow lake in India

Dipankar Ghosh¹, Jayanta Kumar Biswas¹, ²,*

Abstract

This paper evaluates the efficiency of a macroinvertebrate-based Pollution Tolerance Index (PTI) in detecting aquatic pollution in the Chhariganga oxbow lake in India. In this lake, calculated PTIs were compared with results from an array of physicochemical water and sediment parameters and to a macroinvertebrate diversity assessment conducted in parallel for the same lake. The obtained PTI values fell in a range (between 20 and 31) that are indicative of an absence of organic pollution according to the literature, and are normally reported for systems devoid of anthropogenic activity (for instance no monsoonal polluting jute retting activities). However, in the light of the results for the assessed water and sediment physicochemical parameters, and the support of diversity indexes of macroinvertebrates, using data from the same lake, it was possible to conclude that the obtained PTI values do not reflect the true pollution status of this oxbow lake. As PTI values and diversity indexes contradict each other in detecting pollution, it is advised to take both parameters into consideration when using macroinvertebrates to assess aquatic health.

Keywords: aquatic health; diversity indexes; macroinvertebrates; pollution; water quality

Introduction

Macroinvertebrates play an essential role in aquatic habitat food webs (Ziglio et al. 2006). Their high functional and taxonomic diversity, ubiquity, tolerance of wide environmental gradients, rapid, and often predictable response to environment changes of natural and anthropogenic origin make them useful bioindicators of aquatic health status (Rosenberg & Resh, 1993; Bonada et al. 2006). Moreover, macroinvertebrates display a limited migration pattern (with low mobility and generally sessile or sedentary habits)
facilitating their collection and identification (Barbour \textit{et al.} 1999; Ziglio \textit{et al.} 2006). Macroinvertebrates also have long life spans (of several weeks to years), and are thus indicative of changing water qualities by reflecting cumulative effects of the present and past conditions of short- and long-term environmental stressors (EPA, 1998) which became important areas for maintaining biodiversity (Meyer \textit{et al.} 2007; Richardson & Danehy, 2007).

Macroinvertebrates have been widely used as bioindicators in impact studies of environmental perturbations on aquatic ecosystems (Lenat \textit{et al.} 1981; Victor & Ogbeibu, 1985; Ortiz & Puig, 2007; Olomukoro & Dirisu, 2014), water quality assessments (Sharma & Rawat, 2009), and organic and inorganic pollution monitoring studies (Thorn & Williams, 1997; Kazanci & Dugal, 2000). Macroinvertebrates are thus useful to understanding the ecological health of an aquatic ecosystem and can complement, and even become an alternative to, chemical and microbiological analyses, because they are sensitive to short-term fluctuations of the aquatic health (Ravera, 2000; Ikomi \textit{et al.} 2005; George \textit{et al.} 2009; Olomukoro & Dirisu, 2014). Their community assemblages vary in time and space and their diversity within a certain area is related to water fertility and productivity (Latha & Thanga, 2010). Biomonitoring studies employing macroinvertebrates to rate the quality of both lotic and lentic water bodies have been widely reviewed (Ogbeibu & Oribhabor, 2002; Clarke \textit{et al.} 2003; Imoobe & Ohiozebau, 2009; Omoigberale & Ogbeibu, 2010; Birk \textit{et al.} 2012 and Olomukoro & Dirisu, 2012). The ecological assessment of aquatic systems with macroinvertebrates is one of the most frequently used protocols for water quality evaluations in standard water management. Furthermore, macroinvertebrate abundance, community structure, and ecological functions are broadly used to characterize water quality in freshwater ecosystems (Odiete, 1999).

In India, a limited number of studies have used aquatic macroinvertebrates in water quality bioassessment (Nandan, 1997; Balachandran & Ramachandra, 2010; Latha & Thanga, 2010; Alakananda \textit{et al.} 2011; Balachandran \textit{et al.} 2012; Gupta & Narzary, 2013; Kumar & Khan, 2013; Rashid & Pandit, 2014; Doley & Kalita, 2014), and only one has addressed the ecological aspects of macroinvertebrates in an oxbow lake (Chakrabarty & Das, 2006). Nonetheless, the use of aquatic macroinvertebrates to rate the water quality of oxbow lakes in India remains poorly documented and macroinvertebrates, seasonal distribution in relation to physicochemical variables is neither well known in West Bengal oxbow lake ecosystems.
In the present study, in order to evaluate water quality and aquatic health status through seasonal bioassessment in an Indian oxbow lake, a survey and analysis of the seasonal structure of lake macroinvertebrate communities was conducted. Further, the composition and physicochemical parameters of the lake were also assessed. The studied oxbow lake is part of the Ganga river basin in the Nadia district, West Bengal. The core of the macroinvertebrate assessment for this lake consisted of obtaining and analyzing the pollution tolerance index (PTI) as designed by Olomukoro & Dirisu (2014). Thus, the present study is also an opportunity to test the efficiency of this approach in evaluating an Indian water system.

Materials and methods

Study area

The Chhariganga oxbow lake is located in Nakashipara development block of Nadia district, West Bengal, India (23.5779214 °N, 88.3471226 °E). This lake is situated at about 90 Km away from Kalyani university campus, Nadia and nearly 40 km north of the tropic of cancer line. The Chhariganga oxbow lake was formed as an abandoned meander of the river Ganga and is a fresh water, semi-closed oxbow lake that receives water from the Ganga river, during monsoon, through a narrow channel at the north-east corner of a loop of the river. The Chhariganga oxbow lake also stores rain water. This oxbow lake is spread over an area of 58.28 ha with an annual average depth of 2.6 m. The catchment area of the oxbow lake is nearly 600 ha (Fig. 1).

The oxbow lake was selected at random among a total of 122 similar oxbow lakes in Nadia District, West Bengal. There are three distinct annual seasons in this region: pre-monsoon or dry season, from March to June; monsoon, or rainy season, from July to October (within this period jute retting takes place, generally from August to September); and post-monsoon or winter season, from November to February. There have been occasional inundations of the surrounding banks during monsoon. The Chhariganga lake is subjected to all forms of human activities including jute retting during monsoon, agriculture and fishing. It is the only source of irrigation water to the immediate agriculture communities.

The Chhariganga oxbow lake has taken different names in four different development block locations like "Errerdanga Chhariganga", "New Chhariganga" along its largest (about 88.63 ha) segment in Kaliganj, "Bhagirathi Chhariganga" in Nabawip, "Chhariganga" in Nakashipara and
“Chhariganga Oxbow lake” in Santipur covering a total recorded area of 207.20 ha. This lake is important because it accounts for around 8.69% of the total oxbow lake Government area of water bodies and is probably the sole example of a semi-closed type oxbow lake in the district. This oxbow lake has an estimated average effective water spread area (EWSA) of 33.33 ha, that accounts for about 57% of a recorded water body area (RAW) of 58.28 ha, as registered by the land and land revenue department of West Bengal from April 2013 to March 2014. In this 12-month period, flood water entered the lake enhancing its EWSA and its annual average water depth of 2.55 m. Thus, the volume of the EWSA (in millions of tons) was estimated to be 0.42, 1.50, 0.77, 0.85, and 0.90 for pre-monsoon, monsoon, post-monsoon, annual average, and annual total, respectively. The Chhariganga oxbow lake has on average 600 jute retting units of mean size 30 m², with each unit covering about 3.6% of the EWSA (3.09% of RAW) and consuming a water volume of more than 5% of the total EWSA annual average during monsoon (Table 1) Ultimately, the present study focused on 28.13% of the whole Chhariganga’s recorded area (2.44% and 11th largest of the total oxbow lakes as public water bodies in the district) which is in Nakashipara Block.
Table 1. Mean and standard deviation of the water physicochemical variables measured in the Ojo de Agua Uriburu lake between December 2012 and July 2013.

<table>
<thead>
<tr>
<th>OXBOW LAKE'S ATTRIBUTES</th>
<th>PRM</th>
<th>MON</th>
<th>POM</th>
<th>YR AVERAGE</th>
<th>YR TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAW (ha)</td>
<td>58.28</td>
<td>58.28</td>
<td>58.28</td>
<td>58.28</td>
<td>58.28</td>
</tr>
<tr>
<td>RAW (sqm)</td>
<td>582800</td>
<td>582800</td>
<td>582800</td>
<td>582800</td>
<td>582800</td>
</tr>
<tr>
<td>Average Length (m)</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
</tr>
<tr>
<td>Average Width (m)</td>
<td>80</td>
<td>200</td>
<td>120</td>
<td>133</td>
<td>133</td>
</tr>
<tr>
<td>EWSA (sqm)</td>
<td>200000</td>
<td>500000</td>
<td>300000</td>
<td>333333</td>
<td>333333</td>
</tr>
<tr>
<td>EWSA (ha)</td>
<td>20</td>
<td>50</td>
<td>30</td>
<td>33.33</td>
<td>33.33</td>
</tr>
<tr>
<td>Average Depth (ft)</td>
<td>7</td>
<td>10</td>
<td>8.5</td>
<td>8.50</td>
<td>8.50</td>
</tr>
<tr>
<td>Average Depth (m)</td>
<td>2.1</td>
<td>3.0</td>
<td>2.55</td>
<td>2.55</td>
<td>2.55</td>
</tr>
<tr>
<td>Volume of EWSA (m3)</td>
<td>420000</td>
<td>1500000</td>
<td>765000</td>
<td>850000</td>
<td>895000</td>
</tr>
<tr>
<td>Volume of RAW (m3)</td>
<td>1223880</td>
<td>1748400</td>
<td>1486140</td>
<td>1486140</td>
<td>1486140</td>
</tr>
<tr>
<td>Volume of EWSA (million ton)</td>
<td>0.42</td>
<td>1.50</td>
<td>0.77</td>
<td>0.85</td>
<td>0.90</td>
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<tr>
<td>Jute retting units</td>
<td>-</td>
<td>600</td>
<td>-</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Jute retting area per unit (sqm)</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Jute retting Total area (sqm)</td>
<td>-</td>
<td>18000</td>
<td>-</td>
<td>18000</td>
<td>18000</td>
</tr>
<tr>
<td>Jute retting area (ha)</td>
<td>-</td>
<td>1.80</td>
<td>-</td>
<td>1.80</td>
<td>1.80</td>
</tr>
<tr>
<td>Jute retting area % EWSA</td>
<td>-</td>
<td>3.60</td>
<td>-</td>
<td>5.40</td>
<td>5.40</td>
</tr>
<tr>
<td>Jute retting area % RAW</td>
<td>-</td>
<td>3.09</td>
<td>-</td>
<td>3.09</td>
<td>3.09</td>
</tr>
<tr>
<td>volume of water for jute retting (m3)</td>
<td>-</td>
<td>54000</td>
<td>-</td>
<td>45900</td>
<td>45900</td>
</tr>
<tr>
<td>Water required (%) of EWSA for jute retting</td>
<td>-</td>
<td>3.60</td>
<td>-</td>
<td>5.40</td>
<td>5.13</td>
</tr>
<tr>
<td>Water required (%) of RAW for jute retting</td>
<td>-</td>
<td>3.09</td>
<td>-</td>
<td>3.09</td>
<td>3.09</td>
</tr>
</tbody>
</table>
Physicochemical Analyses

Collection of Water and Sediment Samples

For well mixed waters (i.e. water free from any aquatic weed and not isolated by any fishing enclosure), a sample was taken within 1 m below the surface and away from the edge. To collect a sample of the surface layer, a 500 ml polypropylene bottle was held horizontally and half submerged. All samples for chemical analysis were taken between 8 and 9 am of the sampling day. Sediment was collected from different locations and depths of the Chhariganga oxbow lake ecosystem and mixed thoroughly. All collected samples were pooled into one to make a composite sample for chemical analyses.

Water physicochemical parameters

Water physicochemical parameter analyses were carried out during the pre-monsoon, monsoon and post-monsoon seasons (from April 2013 to March 2014). Analyzed parameters for all water samples included: (i) temperature, recorded on the spot with a WTW Multi-parameter portable meter MultiLine® (F/SET-3, Weilheim, Germany); (ii) transparency, assessed with a metallic Secchi disc of 20 cm in diameter with four quadrants of alternate black and white colors on the upper surface. The disc was ballasted on the lower surface and suspended with a graduated cord at its center. (iii) Water pH, measured using a WTW Multi-parameter portable meter MultiLine® (F/SET-3, Weilheim, Germany). For pH, the averaging across samples procedure described by Boyd (1992) was used, pH readings were converted to hydrogen ion concentrations and these were then averaged. (iv) Dissolved oxygen in the lake water was measured with a specific probe of a WTW Multi-parameter portable meter MultiLine® (F/SET-3, Weilheim, Germany). (v) Biochemical oxygen demand (BOD) was obtained following Selvaraj (2005) and Ghosh & Biswas (2015c). This is an in situ method that consisted of filling an 250 ml, airtight bottle and incubating it at in situ temperature for 1 day. Dissolved oxygen (DO) was measured, by the Winkler method, before and after incubation, and the BOD was computed from the difference between initial and final DO. (vi) Chemical oxygen demand (COD) was determined using a digestion mixture of 0.25 N potassium dichromate and concentrated H$_2$SO$_4$ (5:1) with 1 g of AgSO$_4$ and titrating against ferrous ammonium sulphate taking phenanthroline as indicator (Golterman & Ohnstad, 1978).

(vii) Ammonium nitrogen (NH$_4$–N) was measured at 654 nm, following the modified phenate method (Wetzel & Likens, 1991) with a Shimadzu UV-visible spectrophotometer Model UV-1601 (Kyoto, Japan).
(viii) The concentration of nitrite nitrogen (NO$_2$–N) was measured at 543 nm in a spectrophotometer (Shimadzu, Model UV-1601, Kyoto, Japan) using α-naphthylamine and sulphanilic acid (Wetzel & Likens, 1991). (ix) The concentration of nitrate nitrogen (NO$_3$–N) was determined by UV-spectrophotometric method (APHA, 1998) using aluminum hydroxide suspension and 1 N HCL at 220 nm and 275 nm in a spectrophotometer (Shimadzu, Model UV-1601, Kyoto, Japan). The measurement of the ultraviolet absorption at 220 nm enabled rapid determination of nitrate nitrogen, and because dissolved organic matter may also absorb at 220 nm, a second measurement was made at 275 nm to correct the nitrate nitrogen value. (x) Orthophosphate (OP) content of the lake water was determined colorimetrically at 690 nm in a spectrophotometer (Shimadzu, Model UV-1601, Kyoto, Japan) following the stannous chloride method (APHA, 1998). (xi) Total alkalinity was determined by titration of a lake water sample with sulphuric acid (0.02 N). Alkalinity due to hydroxide and carbonate was determined to the first end point (pH 8.3) using phenolphthalein as indicator, and bicarbonate alkalinity was determined to the second end point (pH 4.5) using methyl orange (APHA, 1998). Finally, (xii) water total hardness was determined in alkaline medium with 2-3 drops of eriochrome black-T indicator, by titration against standard 0.01 M ethylene diamine tetra acetic acid (EDTA) until the red wine color of the solution turns pale blue at the end point (APHA, 1998).

**Sediment physicochemical parameters**

Sediment pH of the Chhariganga oxbow lake was measured with a potentiometer upon direct reading using a glass electrode with a saturated KCl-calomel reference electrode (Water resources department, 2009). For estimation of sediment organic carbon, a 500-mg, dried, and powdered sediment sample was taken and digested with 20 ml (1 N) K$_2$Cr$_2$O$_7$ and 20 ml H$_2$SO$_4$ (concentrated) then kept for 30 minutes in a dark place. The sample was then diluted with 150 ml distilled water and 10 ml phosphoric acid, and 1 ml diphenylamine indicator were added to it. The sample was then titrated against 0.5 N ferrous ammonium sulphate (Mohr’s salt) until a brilliant green color appeared.

**Macroinvertebrate Collection, Preservation and Identification**

Macroinvertebrates were collected in each season (pre-monsoon, monsoon, and post-monsoon) in ten different locations in the lake, from April 2013 to March 2014 (Fig. 1). At each sampling location, collections were done using a D-frame net of 0.5 mm mesh size, and consisted of 100 samples in
an area of 1m². Pupae and other macroinvertebrates attached to the bushes were washed into a hand net made of mesh bolting silk of 100 µm. Water was added and stirred vigorously on floating fauna while sieving to handpick the non-floating fauna through a 250 µm mesh sized net. As the depth of the oxbow lake ranges from 0.6 to 3.0 m (Table 1), a dip net was used in shallow water, and an Ekman’s grab in deeper water was used to retrieve sediments from the bottom.

One sediment sample was collected from the bottom in a plastic container of 15 L at each sampling location in the lake in every season (Ghosh & Biswas, 2015b; Obolewski, 2016). All samples collected from the ten different locations were combined into a single composite sample for a particular sample day. Pooled samples were fixed in formaldehyde (4 %) in the field and transferred to 70 % ethyl alcohol for preservation after sorting in the laboratory. Macroinvertebrates were sorted and identified to the family level with the help of identification keys and available literature (Pennak, 1989; Edmondson, 1993; Merrit & Cummins, 1994; Jessup et al. 2003; Subramanian & Shivaramakrishnan, 2005; 2007; Stroud Water Research Centre, 2015) as identification at the family level awards more precision to the taxonomists and requires less expertise and time to complete (Barbour et al. 1999). Considering this, and counted under a stereomicroscope in the laboratory, relative abundance of macroinvertebrates was calculated as percentage composition (%) and their total occurrences in numbers divided by total sampled water volume at each sampling site was referred to as mean macroinvertebrate density (n/m³) for the oxbow lake. The annual mean macroinvertebrate density was obtained as the average macroinvertebrate density of the three sampling seasons.

**Pollution Tolerance Index determination**

Seasonal Pollution Tolerance Index (PTI) for the Chhariganga oxbow lake was obtained following the methodology established by Olomukoro & Dirisu (2014). Briefly, sampled macroinvertebrate families were assigned to three groups, namely pollution intolerant, moderately tolerant, and tolerant. Each category was then scored with a sensitivity factor; a factor of 3 was given to the pollution sensitive (intolerant) group, a factor of 2 to the facultative or moderately tolerant group, and a factor of 1 to the pollution tolerant group. Sensitivity factors of macroinvertebrate families, as defined by Olomukoro & Dirisu (2014), are shown in (Table 2). The products of the number of occurrence of each family by its respective sensitivity factor were summed to obtain the PTI for each sampling point within each sampling season.
Table 2. Pollution sensitivity scores of macroinvertebrate families according to Olomukoro & Dirisu (2014).

<table>
<thead>
<tr>
<th>SL NO</th>
<th>FAMILY</th>
<th>SENSITIVITY SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Elmidae</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Hydrachnidae</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Unionidae</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Viviparidae</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Macromiidae</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Chironomidae</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Ceratopogonidae</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Platycnemididae</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Palaemonidae</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Potamidae</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Corixidae</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Nepidae</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Hydrometridae</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Gerridae</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Hydrophiilidae</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Culicidae</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>Physidae</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>Hirudinidae</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>Lumbricidae</td>
<td>1</td>
</tr>
</tbody>
</table>

Thereafter, obtained PTIs were compared with reference PTIs as shown in (Table 3) (i.e. unpolluted water values between 23 and above, excellent; 17-22 good, 11-16 fair; and below 10 poor).

Data Analyses

Mean, standard deviation and the degree of relationships among different physicochemical factors of water and sediment were determined using linear regression with the help of MS-Excel. The level of statistical significance was accepted at P < 0.05.
Table 3. Water quality rating according to Pollution Tolerance Index values.

<table>
<thead>
<tr>
<th>PTI VALUES</th>
<th>WATER QUALITY RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 23</td>
<td>Excellent (Unpolluted water)</td>
</tr>
<tr>
<td>17-22</td>
<td>Good (Unpolluted water)</td>
</tr>
<tr>
<td>11-16</td>
<td>Fair (polluted water)</td>
</tr>
<tr>
<td>≤10</td>
<td>Poor (polluted water)</td>
</tr>
</tbody>
</table>

Result and discussions

Water and sediment physicochemical variables

In the Chhariganga oxbow lake, according to physicochemical water parameter analyses, except for water transparency, BOD$_1$, NO$_2$–N, and water OP content almost all assessed parameters did not show significant changes throughout the year. Mean annual values for the 12 measured physicochemical variables of the lake, are shown in Table 4 and (Fig. 2a and 2b); sediment pH (6.8 – 7.9, 7.53 ± 0.34) and percent of sediment organic carbon (1.87 – 2.89, 2.17 ± 0.28) in Fig. 3. The highest mean values for BOD$_1$, COD, OP were 4.59 ppm, 86.67 ppm, 0.50 ppm, respectively and were observed during monsoon. Whereas in the same season, when jute retting process gets intensified in the lake, the lowest values of water’s transparency (27.00 cm), pH (7.84), DO (3.63 ppm) and NO$_2$–N content (0.01 ppm) were recorded (Fig. 2a, 2b, and 3). Compared to their values in pre-monsoon, monsoon mean values of the following water quality parameters showed an increase in the following proportions: BOD$_1$ (182.57 %), COD (18.18 %), NH$_4$–N (7.87 %), NO$_3$–N (17.73 %), OP content (167.64 %), sediment organic carbon content (10.11 %), and pH values (7.36 %). Whereas reductions were observed for the following parameters: water transparency (62.54 %), pH (5.74 %), DO (22.16 %), NO$_2$–N (65.68 %), total hardness (21.63 %) and total alkalinity (24.27 %).

During pre-monsoon the Chhariganga oxbow lake experienced the highest mean water transparency (72.07 cm, representing a 78.87 % rise over post-monsoonal mean), water temperature (31.5 °C), total hardness (123.86 ppm, representing a 45.29 % increase over post-monsoonal mean) and total alkalinity (147.64 ppm, 49.64 % hike over post-monsoonal mean).
Figure 2a and 2b. Variation in water parameters.
In addition, the oxbow lake’s lowest values were also observed during pre-monsoon in BOD$_1$ (1.63 ppm, 32.33 % fall in post-monsoonal mean), COD (73.33 ppm, 5.38 % decrease of post-monsoonal mean), NO$_3$–N (0.53 ppm, 53.62 % decrease) of post-monsoonal mean, sediment pH (7.14) and sediment organic carbon (2.08 %). Compared to post-monsoon, during pre-monsoon changes in other parameters were observed: DO (21.91 % decrease), NH$_4$–N (50.75 % decrease) and NO$_2$–N (35.31 % increase), OP (41.17 % increase).

In this lake, during the post-monsoon season the highest recorded parameter mean values were the following: water pH (8.42); DO (5.96 ppm, representing a 64.52 % rise over the monsoonal mean); NH$_4$–N (0.07 ppm, that accounts for an 88.21 % hike on the corresponding monsoonal mean); NO$_3$–N (1.15 ppm); and sediment pH (7.80). Furthermore, also during post-monsoon, the lowest
mean parameter values were observed for water temperature (19.56 °C), OP (0.13 ppm, 73.53 % dip), total hardness (85.25 ppm) and total alkalinity (98.67 ppm). Additionally during post-monsoon, changes respect to monsoon values were observed for NO$_2$–N content (115.34 % increase), COD (10.58 % decrease), BOD$_1$ (47.70 % decrease), transparency (increased by 49.23 %) and sediment’s organic carbon content (5.54 % decrease).

The highest concentrations of NH$_4$–N and NO$_3$–N were observed during post-monsoon and the highest OP values during monsoon. Water transparency mean values showed a sharp decrease as monsoon followed pre-monsoon. During monsoon, the elevated levels of orthophosphate, COD, and BOD$_1$ as well as the reduced levels of DO, water pH, and transparency (Fig. 2a and 2b) were also attributed to the jute retting and influx of turbid water into the oxbow lake ecosystem. A higher variations in sediment organic carbon content (Fig. 3) were noticed during the monsoon due to obvious reason of jute retting.

![Figure 3. Variation in sediment properties.](image-url)
Water and sediment health condition as revealed by physicochemical analyses

Values of the assessed physicochemical parameters for the Chhariganga oxbow lake during monsoon were elevated, compared to their values in pre-monsoon, and the same trend was observed with lake sediment analyses results. Such a general parameter value increase may be due to jute retting and to a high inflow of organic matter. The highest concentrations of \( \text{NH}_4^+ - \text{N} \) and \( \text{NO}_3^- - \text{N} \), observed during post-monsoon, and of OP, recorded during monsoon, may also be due to the allochthonous organic input and decomposition of aquatic macrophytes, as well as to jute retting. The sharp decrease in mean values for water transparency during monsoon compared to pre-monsoon indicate a high level of total dissolved solids due to a heavy load of light penetration restricting organic matter in this lake. Consequently, the concentration of dissolved oxygen decreased due to a reduced photosynthetic rate. The statistically significant changes in water transparency, \( \text{BOD}_1 \), and OP content in the present study can be attributed to an overall organic pollution in the lake throughout the year, and especially during monsoon. This physicochemical parameter study reveals that the high values of parameters like pH, total hardness, total alkalinity, orthophosphate, and the low values of water transparency, DO, BOD, and COD reflect a poor to moderate water quality with a moderate to high organic pollution in the system.

PTI of macroinvertebrates

The present study reported macroinvertebrates of 19 families in 3 phyla. Marcroinvertebrate seasonal occurrence, relative abundance, and pollution tolerance levels are given in Suppl. 1 Relative abundance as percentage composition and seasonal occurrence of individuals classified under different pollution groups (pollution sensitive or intolerant, moderately tolerant, and tolerant) are given in Suppl. 2 and (Fig. 4). Macroinvertebrates of the pollution tolerant group dominated during all three seasons with frequencies of 55.81 %, 90.25 %, and 79.06 %, for pre-monsoon, monsoon and post-monsoon, respectively. While families of the pollution-sensitive or intolerant group were the least frequent during pre-monsoon and post-monsoon, and were absent during monsoon. Macroinvertebrates of moderately pollution tolerant families had their maximum occurrence in the lake during post-monsoon and their minimum occurrence during pre-monsoon. In the Chhariganga oxbow lake, total mean macroinvertebrate density increased during the monsoon season compared to the other two seasons. Pollution tolerant and moderately tolerant macroinvertebrate groups
largely contributed to total mean density throughout the study, and intolerant groups were substantially reduced or absent during monsoon. This was due to an elevated organic pollution resulting from the jute retting process and a monsoonal influx of turbid water from the river Ganga (Fig. 4) and (Suppl. 2).

Detailed relative abundance as percentage composition, seasonal occurrence of family (richness), and pollution tolerance indexes of macroinvertebrates are given in Suppl. 3 and (Fig. 5). The richness of intolerant group was zero during monsoon (Fig. 5 and Suppl. 3). Leeches, as a pollution tolerant group, were only encountered in the post-monsoon sampling. They may not have been seen during rest of the year due to the profundity of the lake, high water turbidity (from the River Ganga during monsoon), and to the better pre-monsoonal environmental condition. Additionally, a limited sample size may be an additional reason why in the present study leaches were only found during post-monsoon. (Fig. 6) demonstrates the macroinvertebrate taxa frequency distributions in the lake ecosystem. The phylum Arthropoda - class Insecta had the biggest share among all observed phyla (Fig. 6).

In the light of another study conducted in parallel for the same water system (Ghosh & Biswas, 2015 b), macroinvertebrate density and standing biomass in
the Chhariganga oxbow lake were observed to be strongly and positively correlated with the lake’s BOD, orthophosphate content, and sediment organic content. Macroinvertebrate richness was positively correlated with water NO$_3$–N content, and macroinvertebrate Shannon Weiner Diversity Index (SWI) values with water pH. Inverse correlations were found between macroinvertebrate density and both water transparency and pH level; and between water orthophosphate content and macroinvertebrate SWI values.

**Aquatic health assessment based on PTI**

PTIs obtained in the present study differ considerably from those obtained from the assessment of the health status of the wetlands in Southern Nigeria (Olomukoro & Dirisu, 2014). The obtained high PTIs (Suppl 2) suggest that during pre-monsoon and post-monsoon, water in the lake was in an excellent and unpolluted condition; whereas the slightly lower PTI values obtained during the monsoon, and throughout the year, are indicative of a good and unpolluted water with low or no anthropogenic activity.

![Taxon richness distribution per pollution tolerance group.](http://ciencias.javeriana.edu.co/investigacion/universitas-scientiarum)

**Figure 5.** Taxon richness distribution per pollution tolerance group.
Water health condition as revealed by biodiversity indices

Obtained PTI values in this study do not concur with the poor health status of the lake as revealed by the low values of the SWI and Simpson diversity index (ranging from 0.29 to 2.12) for macroinvertebrates (Suppl. 4). These two indexes were calculated with the same data of the present study but were published elsewhere (Ghosh & Biswas, 2015 b). Their low values reflect an overall bad-to-poor state of the lake’s health, a poor water quality, especially during monsoon, and can be attributed to high intensity jute retting activity. The conclusion of a poor health status, drawn from these macroinvertebrate diversity indexes, is also supported by the findings of previous studies, on the same lake, in which low diversity index values were obtained for rotifers (Ghosh & Biswas, 2014), zooplankton (Ghosh & Biswas, 2015 a), macrophyte (Ghosh & Biswas, 2015 d), phytoplankton (Ghosh & Biswas, 2015 e), fish (Ghosh & Biswas, 2017 a; 2017 c), and fish productivity (Ghosh & Biswas, 2017 b). Because of their tolerance to pollution, Oligochaetes are important bioindicators and provide a criterion for an ecological lake classification (Rashid & Pandit, 2014). As deposit feeders, their presence in the Chhariganga
oxbow lake is an indication of organic matter richness, and their tolerance to silting and decomposition confirms the degree of organic pollution in the system caused by jute retting.

Conclusions

The pollution status of lake Chhariganga, as revealed by the obtained PTIs, is not corroborated by the macroinvertebrate diversity assessment derived from the same data, nor is it further supported by the results of rotifer, zooplankton, macrophyte, and phytoplankton studies, conducted by Ghosh & Biswas (2015 b) in parallel with the present study. Physicochemical analyses too confirmed the precarious to poor state of the lake’s health. The presence of earth worms throughout the year also confirmed the lake’s organic pollution. Therefore, we conclude that macroinvertebrate PTI values alone are not reliable aquatic health diagnostic tools unless they are complemented or contrasted to diversity indexes (e.g. SWI). However, ecological studies of macroinvertebrates are still necessary to understand lake ecosystems and their health. There remains a need to prevent, or regulate the intensity of, jute retting activity in the lake during monsoon in order to ensure a sustainable management and conservation of this aquatic environment and to enhance its biodiversity. The present study provides pivotal baseline data to various organizations, government, non-government agencies, as well as academic institutions to take actions that improve and lead to a more efficient and sustainable management of oxbow lakes.

Conflict of interest

The authors declare having no conflict of interest on any aspect of the research and results of the present work. The authors hereby pronounce no competing interests.

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Pollution Tolerance Index in a lake in India

Resumo. Este artigo avalia a eficiência do Índice de Tolerância a Contaminação baseado em macroinvertebrados (PTI) para detectar contaminação aquática no lago em ferradura Chhariganga, Índia. Os PTIs calculados foram comparados com resultados de um conjunto de parâmetros físico-químicos da água e do sedimento, e com uma determinação da diversidade de macroinvertebrados realizada paralelamente para o mesmo lago. Os valores obtidos para PTI cayeron dentro de um rango (entre 20 e 31) que indica, de acordo a literatura, a ausência de contaminação orgânica, e que são normalmente reportados para sistemas desprovidos de atividade antropogénica (por exemplo, atividades contaminantes de enriamento do yute durante os monzones). Sin embargo, a luz de los resultados de los parámetros físico-químicos de agua y sedimento, y con el soporte de los índices de diversidad de macroinvertebrados usando datos del mismo lago, foi possível concluir que los valores de PTI obtenidos no reflejan el verdadero estado de contaminación del lago en ferradura. Como los valores de PTI y los índices de diversidad se contradicen entre si en detectar la contaminación, se aconseja tomar en consideración ambos parâmetros cuando se usen macroinvertebrados para determinar la salud acuática.

Palavras-chave: saúde aquática; índices de diversidade; macroinvertebrados; contaminação; qualidade da água
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