Categories and Water Quality of Artificial Water Storage Ponds in Rural Areas of Khulna, Bangladesh

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ABSTRACT
Artificial water storage ponds in the rural area around Khulna and Bagerhat Districts in Bangladesh were surveyed and categorized into domestic use (denoted as D), wastewater storage use (W), agriculture use (A) and fisheries use (F) for the rural ponds and urban domestic use (U: divided into large (Ul) and small groups (Us)). The main survey was carried out during the wet season and a part of the surveyed ponds was also investigated during the dry season. The area and volume of the ponds were large in Ul and F. The transparency was low in the category F, W and U ponds and the SS, TOC were higher in the category F and U ponds than the others. On the other hand the T-N and T-P were higher in category W and U ponds than the others. The size of all the ponds was decreased and the pond water changed more turbid during the dry season caused by increase of particulate matter in the water. The principal component analysis showed that the first component indicating the progress of eutrophication was largely contributed. The water quality of in rural domestic ponds especially during the dry season should be improved.

Keywords: pond categorization, seasonal change, water quality, water storage pond

INTRODUCTION
Many artificial water storage ponds are used in developing Asian countries. Water is stored in these ponds and usually used directly on-site (Meester et al., 2005). It is important to maintain a certain pond water quantity and quality to ensure it is suitable for its intended purpose. Pond water is not usually used for drinking, but it is used for other domestic purposes including as an agriculture water resource in aquaculture areas (Kazi, 2003).

Bangladesh possesses enormous wetland areas equal to roughly 11 percent of the total area of the country (Rasheed, 2008). The land is sometimes flooded during the monsoon season. People construct artificial storage ponds by simply building embankments to enclose water during the dry season so that they can use the pond water for various purposes, especially in rural areas. Pond water is considered one of the most important water resources in these areas.

The Khulna and Bagerhat Districts are located on a delta in the southwestern part of Bangladesh near a mangrove forest and the Bay of Bengal. The districts are supposed to be very vulnerable to climate change (Asian Development Bank, 2011). The water resource system in the area must be improved to be better able to adapt to the water crisis caused by climate change. Rural people use pond water as well as groundwater in these districts. They also possess wide area ponds that are used for aquaculture (Dey et al., 2008; Department of Fisheries, Bangladesh, 2011). Although the pond water in the...
district plays an important role as a water resource in the area, little research has been conducted to determine its water quality, characteristics and the seasonal changes caused by the differences in precipitation during the wet and dry seasons (Bangladesh Bureau of Statistics, 2013).

The purpose of the study is to understand the water quality and problems with water usage of the ponds in the rural areas around the Khulna and Bagerhat Districts in Bangladesh. The topics addressed herein include:

(1) The categories of water usage for water storage ponds.
(2) The size and water quality in the ponds and their seasonal changes.
(3) The factors affecting the water quality in the ponds and any issues that need improvement.

MATERIALS AND METHODS
Surveyed area
Pond water characteristics were surveyed in the urban and rural areas near Khulna City, Bangladesh (Khulna City and Rupsa, Fakirhat and Mollahat villages (Fig. 1)). A significant number of natural wetlands and artificial ponds cover the area (Chowdhury and Mamun, 2006). The ponds in the villages are used for many purposes: rural domestic uses including dish washing, laundry, bathing, cooking (Sultana and Crow, 2000), wastewater storage use, agriculture use (paddy fields) especially in Rupsa and Mollahat and fishery use (prawns and fish) in Fakirhat. The village people use well water (which is partially contaminated with arsenic) for drinking and cooking (Shafiquzzaman et al., 2009). Tap and bottled water are also used in urban areas (Khulna City) where people use both pond and well water for their domestic use. The ponds in the urban areas are also used for vehicle washing, recreation and wastewater discharge. Monthly precipitation is almost 100 – 400 mm from the period from May to October (during the wet season) and is less than 100 mm from the period from November to April (during the dry season, Bangladesh Bureau of Statistics, 2013). The daily maximum temperature is less than 30°C in only December, January and February (Shahid, 2011) and is higher than 30°C during all the other months (Bangladesh Bureau of Statistics, 2013).

Pond categorization
The surveyed rural ponds were clearly divided into four kinds of usage: domestic water use, wastewater storage use, seasonal agriculture use and fishery use. So we defined 4 pond categories in the surveyed area by their usages as follows and denoted them as D, W, A and F. The ponds in the urban areas were divided into domestic use (denoted as U) and other various usages (wastewater storage, vehicle washing, and recreational use). Because the number of ponds in urban area not for domestic use was small, we defined only 1 pond category denoted as U by adding to the rural pond categories as follows.

The definitions of 5 pond categories of the surveyed area in this paper:

(1) D: A pond that is used for bathing, laundry, dish-washing or other domestic use.
(2) W: A pond that is used for storage of wastewater.
(3) A: A pond that is used for paddy cultivation during dry season. (Most of them are used for fish cultivation during wet season in the area.)

(4) F: A pond that is used for fish and prawn cultivation during all seasons.

(5) U: A pond that is situated in urban area and used for the same purpose as D.

**Wet and dry season survey**
The numbers of surveyed ponds in the five categories corresponding to D, W, A, F and U were 35, 12, 19, 20 and 20. The survey was carried out during the wet season during September 2012, as shown in Table 1. To take into account the differences between the wet and dry seasons, a portion of the surveyed ponds (49 ponds) were also investigated during February and March 2013 (dry season, see Table 1). The number of ponds used during the dry season was almost half that as during the wet season with the exception of a single W pond because the rest of these ponds lost water and dried out. The number of surveyed ponds and their percentages during both wet and dry season in Khulna City and in the three villages are shown in Table 2. The percentages of the surveyed ponds were 31, 18, 21 and 29% during wet season and 27, 12, 20 and 41% during dry season in Khulna, Rupsha, Fakirhat and Mollahat, respectively. The percentage of surveyed ponds in the four surveyed area were almost the same during both season except Mollahat during dry season.

**Pond size and water quality measurement**
The surveyed ponds were all artificial ponds which normally made in rectangular form. The length and width of the surveyed ponds were measured using a laser distance meter (DISTO X310, Leica, Germany). Their water depth was directly measured or estimated by interviewing the owners or local people. The areas and volumes were estimated from their lengths, widths and depths. Because the area and the depth of the pond largely
decreased during the dry season, the remaining surface area and decreased depth were measured.

Because it was difficult to take sample water inside of the ponds, surface water that seemed uninfluenced by bank and bottom mud, water weed and floating matters was carefully selected and taken from the pond side. Temperature, pH, DO, ORP, EC and transparency of the sample water were measured by portable meters (D-54SE, HORIBA, Japan, and HQ30D, HACH, USA) on-site. The collected sample in a 1 L plastic bottle was brought to the laboratory in Khulna University of Engineering and Technology where SS was measured immediately. Two hundred and fifty mL samples were transferred in other plastic bottles and they were stored in a refrigerator until the transportation to Japan. No acid was added to the sample during the one day transportation. In Japan rest of all laboratory analysis (including examinations of TOC, T-N, T-P, PO₄-P and alkalinity using the JIS K0102 (Japanese Standards Association, 2013) and Shimadzu TOC-V WP) was carried out. Statistical analysis (normality, F-test, t-test etc.) also carried out to compare different categories of pond groups.

**Principal component analysis**

The correlation matrix of the 12 water quality items (on-site tests and laboratory analysis) derived from the samples was calculated. Eigenvalues and eigenvectors of the correlation matrix were estimated using the power method (Hoffman, 1992). Factor loadings for the principal components and their contribution ratios were then obtained from the eigenvalues and eigenvectors. Finally, the principal component scores of the samples were calculated.

### Table 1 - Numbers of the different categories of surveyed ponds.

<table>
<thead>
<tr>
<th>Rural area</th>
<th>Domestic (D)</th>
<th>Wastewater Storage (W)</th>
<th>Agriculture (A)</th>
<th>Fisheries (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet season</td>
<td>35</td>
<td>12</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Dry season</td>
<td>16</td>
<td>1</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Urban area</th>
<th>Domestic (U)</th>
<th>Others*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet season</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>Dry season</td>
<td>8</td>
<td>-</td>
</tr>
</tbody>
</table>

* Wastewater, vehicle wash, recreational use

### Table 2 - Numbers and percentages of the surveyed ponds in different areas.

<table>
<thead>
<tr>
<th></th>
<th>Khulna</th>
<th>Rupsa</th>
<th>Fakirhat</th>
<th>Mollahat</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet season</td>
<td>35 (31%)</td>
<td>20 (18%)</td>
<td>24 (21%)</td>
<td>33 (29%)</td>
<td>112 (100%)</td>
</tr>
<tr>
<td>Dry season</td>
<td>13 (27%)</td>
<td>6 (12%)</td>
<td>10 (20%)</td>
<td>20 (41%)</td>
<td>49 (100%)</td>
</tr>
</tbody>
</table>
Results and Discussion
Pond sizes during the wet season

The areas and volumes of the ponds varied according to the different categories. The average and standard deviation of volume, area and depth of the category D, W, A, F and U ponds are shown in Fig. 2. Although the standard deviation of each pond category was large, the differences between the five categories were statistically clear. Because U ponds were divided into two (large and small) groups, they were statically analyzed by dividing into the large group (Ul) and the small group (Us). The area was largest in Ul ponds and secondarily large in F and A ponds. The area of Ul of which average was greater than 10,000 m² showed significant difference from the area of category F and A ponds ($p < 0.001$). Ul ponds were used for not only domestic water usage but also recreational and landscape use in the urban area. That is the reason why Ul ponds possessed such large area. No difference between category F and A ponds ($p > 0.05$) was found and their averages were greater than 2,000 m². Because A ponds were used as paddy field mainly in dry season, they had suitable size for paddy cultivation. The average area of F ponds was slightly smaller than the reported area in the same district (Chowdhury and Ahmed, 2012) and within the reported area in eastern Bangladesh that ranged between 2,000 to 5,000 m² (Siddique et al., 2012). Rice was already harvested in the paddy fields in category A ponds at the time of the survey and these ponds were already covered with water. Moreover, fish were cultivated in some of the category A ponds as reported by Islam et al. (2004) and Roy et al. (2013). They reported that category A ponds cultivate fish during wet season and cultivate paddy during dry season in the same area. The area of A ponds was larger than category D ponds ($p < 0.05$) and the area of D ponds (an average of < 1,000 m²) was larger than W ponds ($p < 0.001$). The Us ponds and D ponds showed similar distribution and the averages area were not significantly different ($p > 0.05$). The average depth of the five categories did not differ significantly ($p > 0.05$) and was approximately 1 m as shown in Fig.2.

Fig. 2 - Pond size during the wet season (*Ul uses the secondary axis (right side); error bar shows standard deviation).
The volumes of the pond were large for the category F and Ul ponds (average > 2,000 m³) and have no significant difference between them (p > 0.05). The volume of F category pond was significantly larger than category D (p < 0.001), A (p < 0.05), W (p < 0.001) and Us (p < 0.005) ponds. Fishery ponds required enough volume for the cultivation of prawns and fish. Additionally, their depth needed to be shallow enough for the fishermen to walk in the ponds to maintain and catch fish. Large domestic ponds in urban areas (Ul) were large compared to the rural domestic ponds (D). Most of the Ul ponds were used by many people and families at the same time, whereas most of the D ponds were used by only one family. The pond volumes for category A, Us and D ponds had no significant difference between them (p > 0.05) and their averages being 1,600, 1,300 and 940 m³, respectively. The D pond water amount decreases during dry season (November to April). So the D pond volume during the wet season must be larger than the volume that can keep water at the end of the dry season after the water decrease during dry season. The pond volume for category W ponds was significantly small (average < 300 m³, p < 0.005) compared to the other categories.

**Water quality during the wet season**

The average temperatures in the five pond categories were all approximately 30°C. The average pH values ranged from 7.4 – 7.7. Although the differences by category were small, the pH values were rather highest (p < 0.01) in category A ponds than others. The DO and ORP results had no significant difference (p > 0.05) between different category and showed aerobic conditions in all the ponds. However, the aerobic conditions were less in category W ponds than the others.

The averages of the EC for category D, W, A, F and U ponds were 1.3, 12, 0.54, 2.1 and 0.68 mS/cm, respectively. The EC in category W ponds was high because these were contaminated with toilet waste containing high salinity. Category F ponds were divided into two groups that exhibited an EC of 0.30 – 1.4 mS/cm (0.84 ± 0.33 mS/cm; average ± standard deviation) and 2.0 – 5.7 mS/cm (3.1 ± 1.0 mS/cm). The average EC of the 15 shallow tube wells water in the area (Rupsa, Fakirhat and Mollahat) ranged from 0.7 to 1.2 mS/cm except one well (Hasan et al., 2012). Therefore EC of the former group was close to the well water. So we considered the former group as fresh water ponds in this paper, while the latter pond group seemed to contain partly saline water were called as blackish water. Culture fishery includes a variety of fish, shrimp and prawn harvests from ponds in the greater Khulna district using both fresh and saline water (Rasheed, 2008). The EC exhibited a positive correlation (r = 0.63) to the pond sizes except one large freshwater pond. The average volume of blackish water ponds was 3,318 ± 1,189 m³ which was significantly larger (p < 0.001) than the average volume of fresh water ponds (1,364 ± 735 m³). This corresponded to the fact that the average farm size for bagda (Tiger Shrimp) grown in saline conditions was larger than that for golda (Giant Prawns) grown in freshwater (Rasheed, 2008).

The average, standard deviation, maximum and minimum values for the transparency, SS, TOC, T-N and T-P are shown in Table 3. The average and minimum transparencies were small (p < 0.001) in category F, W and U ponds. The average SS was significantly large (p < 0.01) in category F and U ponds where the water was greenish colored and the low transparency appeared to be the result of significant algal growth. The low transparency of the category W ponds may be caused by the polluted wastewater.
containing human excreta. The transparency was significantly larger \((p < 0.05)\) and the SS was low in category A and D ponds, suggesting a cleaner water quality compared to the other categories. The TOC was also significantly high \((p < 0.05)\) in category F and U ponds, whereas it was low \((p < 0.05)\) in category A and D ponds.

The T-N and T-P were significantly high in category W and U ponds than other categories ponds \((p < 0.05)\). Whereas T-N and T-P were significantly lower in category A ponds \((p < 0.05)\) compared to the others. Wastewater, especially human excreta containing high amounts of nitrogen and phosphorus would explain the increase in the T-N and T-P in category W ponds. Only small amounts of wastewater were found to be discharged directly into the domestic ponds in the urban areas (U). U ponds were situated in urban area where presence of livestock was little. However, some ponds were very near to the toilet as well as drainage. These ponds have high risk of contamination by toilet or drainage channel wastewaters which increase T-P and T-N of pond water. Moreover, wastewater discharging into drainage channels in the city often flowed out or infiltrated into the groundwater. Polluted water containing nitrogen and phosphorus would increase the T-N and T-P concentrations in category U ponds. Such pollution of the pond by wastewater suggested the pathogenic contamination, although it was not measured in this survey. People directly use U ponds water (as same as D pond) for hand washing, washing of cloths and dishes, bathing etc. These water uses make direct contact with their skin and affect their health by waterborne disease like skin disease, diarrhea, dysentery, cholera, fever etc. (Haque et al., 2010). They reported that skin disease, diarrhea, dysentery were the first rank disease in Khulna district where 77.14% people use pond water as cooking water, washing and bathing purpose.

<table>
<thead>
<tr>
<th></th>
<th>Domestic (D)</th>
<th>Wastewater storage (W)</th>
<th>Agriculture (A)</th>
<th>Fisheries (F)</th>
<th>Urban domestic (U)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transparency (cm)</strong></td>
<td>Avg ± SD 47 ± 19</td>
<td>27 ± 15</td>
<td>51 ± 21</td>
<td>26 ± 8</td>
<td>40 ± 29</td>
</tr>
<tr>
<td></td>
<td>Max 80</td>
<td>60</td>
<td>110</td>
<td>45</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>Min 20</td>
<td>10</td>
<td>25</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td><strong>SS (mg/L)</strong></td>
<td>Avg ± SD 12 ± 10</td>
<td>14 ± 16</td>
<td>7.8 ± 6.5</td>
<td>29 ± 19</td>
<td>22 ± 22</td>
</tr>
<tr>
<td></td>
<td>Max 53</td>
<td>55</td>
<td>24</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Min &lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>6</td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>TOC (mg/L)</strong></td>
<td>Avg ± SD 7.8 ± 2.9</td>
<td>10 ± 9.6</td>
<td>7.3 ± 3.3</td>
<td>12 ± 3.6</td>
<td>9.9 ± 3.5</td>
</tr>
<tr>
<td></td>
<td>Max 16</td>
<td>41</td>
<td>17</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Min 2.6</td>
<td>4.4</td>
<td>3.7</td>
<td>5.4</td>
<td>4.3</td>
</tr>
<tr>
<td><strong>T-N (mg/L)</strong></td>
<td>Avg ± SD 1.03 ± 0.56</td>
<td>2.16 ± 3.43</td>
<td>0.59 ± 0.28</td>
<td>1.61 ± 1.01</td>
<td>2.11 ± 1.16</td>
</tr>
<tr>
<td></td>
<td>Max 2.83</td>
<td>13.2</td>
<td>1.37</td>
<td>4.68</td>
<td>4.28</td>
</tr>
<tr>
<td></td>
<td>Min 0.31</td>
<td>0.42</td>
<td>0.34</td>
<td>1.12</td>
<td>1.53</td>
</tr>
<tr>
<td><strong>T-P (mg/L)</strong></td>
<td>Avg ± SD 0.17 ± 0.25</td>
<td>0.88 ± 0.74</td>
<td>0.03 ± 0.03</td>
<td>0.13 ± 0.25</td>
<td>0.64 ± 0.45</td>
</tr>
<tr>
<td></td>
<td>Max 1.10</td>
<td>2.73</td>
<td>0.09</td>
<td>1.12</td>
<td>1.53</td>
</tr>
<tr>
<td></td>
<td>Min 0.01</td>
<td>0.01</td>
<td>&lt; 0.01</td>
<td>0.01</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>
The T-N and T-P values in category F and D ponds were also greater than the eutrophication level. The nitrogen and phosphorus seemed to be added into category F ponds as fish feed or chemicals used during cultivation. Actually it is reported that people input fertilizer into F ponds in the area (Islam et al., 2004; Roy et al., 2013). The T-N and T-P concentrations in category A ponds were very low compared to the others.

**Changes in pond size and water quality during the dry season**

The rainfall amount entering the ponds during the dry season was very small compared to the wet season. The decrease in precipitation changed the pond size (depth, area and volume) significantly. The volumes of all the ponds surveyed during both seasons exhibiting a large decrease ($p < 0.05$) were compared, as shown in Fig. 3. The decrease of volume for category A and W ponds was especially large. For category W, only one pond was surveyed and it retained no water. Water was removed in the central parts of category A ponds where rice was planted. Pond water in category A remained only in the surroundings of the rice fields. The ratio of the volume of category A ponds during the dry season to that during the wet season was $0.304 \pm 0.288$ (average $\pm$ standard deviation). The volume of category D, F and U ponds during the dry season decreased to less than half of the volume during the wet season ($0.421 \pm 0.175$, $0.477 \pm 0.277$ and $0.495 \pm 0.197$, respectively).

![Fig. 3 - Pond volume comparison during the dry and wet seasons.](image-url)
The temperature is low from November to February in the area surveyed. Because the survey during the dry season was carried out in February and March, the pond water temperature was a slightly lower (approximately 4°C lower) than during the wet season. A comparison of the transparency, SS, TOC, T-N and T-P during the wet and dry seasons is shown in Fig. 4. The transparency was significantly decreased \( (p < 0.001) \) and the concentration of SS, TOC, T-N and T-P were significantly increased \( (p < 0.001, \ p < 0.005, \ p < 0.001 \) and \( p < 0.01 \), respectively) during the dry season. The transparency during the dry season drastically decreased to almost half of the transparency during the wet season with the exception of a few ponds in categories D and U. The comparison of SS, TOC, T-N and T-P during the two seasons shown in Fig. 4 exhibited the regression lines having the slopes of 2.37, 2.23, 1.60 and 2.17, respectively. The result that the slopes were almost same and around 2 suggested that the increase of TOC, T-N and T-P was related to the increase of SS. The average weight ratio of C:N:P was 100:13:2 during the wet season and 100:16:3 during the dry season. Those ratios were close to the weight ratio \((100:17.6:2.4)\) of nominal composition of plankton such as \( \text{C}_{106}\text{N}_{16}\text{P} \) (Redfield ratio; Redfield, 1934). Although chlorophyll pigment was not measured, the greenish color of the pond water suggested that the particulate matter mainly consisted of phytoplankton community. Chowdhury and Mamun (2006) reported high abundance of Cyanophyceae in two fishponds in Khulna during dry season. Affan et al. (2005) reported that chlorophyll \( a \) concentration in a pond of central Bangladesh became higher in March (dry season) than the concentration in September (wet season). Hossain et al. (2008) also reported that total phytoplankton abundance was higher in dry season (January - March) in northern part of Bangladesh.

The increase of SS and phytoplankton in the surveyed ponds during the dry season seemed to be related to the change of their sizes. It was suggested that the decrease of volume of the ponds caused the increase of nutrients concentration and productivity resulting in the high algal growth in the ponds. Moreover bottom sediment would flow up because of the water turbulence in some shallow ponds when their depth decreased during the dry season.
The contribution ratios from the first, the second and the third principal components (Z1, Z2 and Z3) were 0.38, 0.13 and 0.11, respectively, as shown in Fig. 5. The contribution ratio of Z1 was large compared to the others and Z1 was responsible for almost 40% of the variances in the water qualities. The cumulative contribution ratio of Z1, Z2 and Z3 was 0.62, showing that two thirds of the variances in the 12 items examined were described by the three principal components.

The factor loadings for Z1, Z2 and Z3 are shown in Table 4. The Z1 factor loadings were large for the pH, DO, transparency (negative), SS, TOC, T-N, T-P, and PO$_4$-P.

**Fig. 4 - Comparison of transparency, SS, TOC, T-N and T-P during the wet and dry seasons.**

**Principal component analysis of the water quality**

The contribution ratios from the first, the second and the third principal components (Z1, Z2 and Z3) were 0.38, 0.13 and 0.11, respectively, as shown in Fig. 5. The contribution ratio of Z1 was large compared to the others and Z1 was responsible for almost 40% of the variances in the water qualities. The cumulative contribution ratio of Z1, Z2 and Z3 was 0.62, showing that two thirds of the variances in the 12 items examined were described by the three principal components.

The factor loadings for Z1, Z2 and Z3 are shown in Table 4. The Z1 factor loadings were large for the pH, DO, transparency (negative), SS, TOC, T-N, T-P, and PO$_4$-P.
This suggested that Z1 indicated the trophic states of the ponds showing the eutrophication progress including the nutrient increase and algal growth (SS increase and transparency decrease) caused by photosynthesis.

The Z2 factor loading was large for the EC (negative) and phosphorus. Fig. 6 showed the scores for each sample on the Z1-Z2 plane. It was clear that the Z2 scores were positive for category W and U ponds and was negative for category F ponds during the dry season. As mentioned, category W and U ponds were influenced by wastewater contamination, resulting in high T-N and T-P values. Therefore, Z2 appeared to represent the influence of wastewater contamination.

![Fig. 5 - Cumulative contribution ratio.](image)

<table>
<thead>
<tr>
<th>Factor loading</th>
<th>Z1</th>
<th>Z2</th>
<th>Z3</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>0.543</td>
<td>-0.403</td>
<td>0.343</td>
</tr>
<tr>
<td>Temp</td>
<td>-0.306</td>
<td>-0.029</td>
<td>0.747</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>0.379</td>
<td>0.112</td>
<td>-0.127</td>
</tr>
<tr>
<td>DO</td>
<td>0.561</td>
<td>-0.422</td>
<td>0.466</td>
</tr>
<tr>
<td>ORP</td>
<td>-0.167</td>
<td>-0.066</td>
<td>0.397</td>
</tr>
<tr>
<td>EC</td>
<td>0.309</td>
<td>-0.456</td>
<td>-0.352</td>
</tr>
<tr>
<td>Transp</td>
<td>-0.501</td>
<td>0.367</td>
<td>0.384</td>
</tr>
<tr>
<td>SS</td>
<td>0.745</td>
<td>-0.274</td>
<td>-0.081</td>
</tr>
<tr>
<td>TOC</td>
<td>0.892</td>
<td>-0.132</td>
<td>0.089</td>
</tr>
<tr>
<td>T-N</td>
<td>0.924</td>
<td>0.139</td>
<td>0.093</td>
</tr>
<tr>
<td>T-P</td>
<td>0.808</td>
<td>0.557</td>
<td>0.075</td>
</tr>
<tr>
<td>PO4-P</td>
<td>0.689</td>
<td>0.669</td>
<td>0.046</td>
</tr>
</tbody>
</table>
The Z3 factor loading was large for the temperature. Because the temperatures were higher during the wet season and lower during the dry season, the sample scores for the two seasons were clearly separated in the Z1-Z3 plane, as shown in Fig. 7. Therefore, Z3 seemed to respond to the seasonal influences.

Figure 8 shows the average and standard deviations for the Z1 scores in the five pond categories during the wet and dry seasons. The increase in Z1 was clear during the dry season and suggested an increase in the trophic state in ponds D, A, F and U. Nutrients are generally necessary for paddy and fish production. Nutrients such as cow dung and urea are also added in F ponds to increase fish production in the same area (Chowdhury and Mamun, 2006). Therefore progress of the eutrophication during dry season seems to matter little to A and F ponds. For these reason the increase of Z1 score didn’t have serious problems on A and F ponds.

According to the increase of Z1 during dry season indicating the increase of SS and turbidity in the D and U ponds, the risk of contamination of pathogenic microorganisms would increase during the dry season and cause human health risk because some of them grow on particulate matter (Tortora et al., 1992) and get longer survival (Maier et al., 2009). Bacterial abundance has positive correlation with primary production in water bodies (Cole, 1982) and microbial attachment with SS is common in aquatic ecosystems (Pearl, 1975). For these reason the water quality in D and U ponds should therefore be improved especially during the dry season.

Fig. 6 - Scores for the pond water on the Z1-Z2 plane (Circle: D, Rhombus: A, Square: F, Asterisk: W, Triangle: U, Black: wet season and White: dry season).
However, it has been difficult to introduce any technologies to improve the water quality of the ponds. According to our survey results the high turbulence or SS is the most serious problem of the pond water quality. Therefore filtration process seemed to be effective to separate them. Instead of improvement of the pond water quality, the government and NGOs have installed pond sand filter (PSF) which is used for purification of D ponds water (Harun and Kabir, 2013). But this system also has high installation and maintenance cost (UNEP, 1998) and most of the present users of PSF are not satisfied (50% partially dissatisfied and 30% dissatisfied) with this system due to poor PSF water quality for lack of maintenance, long waiting time, long distance from home etc. (Shafiquzzaman et al., 2009; Harun and Kabir, 2013). Low cost treatment system therefore need to explore which can treat the pond water with low maintenance and affordable to the local people.

Fig. 7 - Scores for the pond water on the Z1-Z3 plane (Circle: D, Rhombus: A, Square: F, Asterisk: W, Triangle: U, Black: wet season and White: dry season).
CONCLUSIONS

(1) The surveyed ponds were categorized into domestic use (D), wastewater storage (W), agricultural use (A), and fisheries (F) in rural area and domestic use (U) wastewater storage, vehicle washing and recreational use in urban areas. U ponds was divided into two group as urban domestic large (Ul) and urban domestic small (Us).

(2) The area of the ponds was Ul > F > A > (D = Us) > W and volume of the ponds (Ul = F) > (A = D = Us) > W during the wet season. The average depth of the five categories did not change significantly and was approximately 1 m.

(3) The transparency was low in the category F, W and U ponds and the SS, TOC were high in the category F and U ponds than the others. On the other hand the T-N and T-P were higher in category W and U ponds than the others. The low transparency in the F and U category ponds seemed to be caused by high rates of algal growth.

(4) The size of all the ponds decreased during the dry season. Transparency during the dry season drastically decreased to almost half that during the wet season. The pond water became more turbid during the dry season resulting from an increase of primary production.

(5) The principle component analysis showed that the contribution ratio of the first component (Z1) was large compared to the others. The Z1 factor loadings suggested that it described the eutrophication progress (trophic states).

(6) The increase of Z1 during the dry season in D and U ponds suggested that water quality improvement is necessary.

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