Physical, chemical and microbiological aspects during the dry and rainy seasons in a pond covered by macrophyte used in aquaculture water supply

Aspectos físico-químicos e microbiológicos nas estações de seca e chuva em viveiro coberto por macrófitas usado no abastecimento de água para aquicultura

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Abstract: Aim: The water quality of a pond covered by macrophytes and used as a water supply for aquaculture was evaluated during the dry and rainy seasons; Methods: Six points were established for water sampling, at water inflow and outflow. Samplings were carried out monthly between June 2008 and May 2009; Results: Inflow points P₁, P₂ and P₃ in the pond had higher nutrient concentrations and high trophic rates. Moreover, capybaras in the area caused sediment suspension and an increase in fecal coliforms. There was significant difference (p < 0.05) in the concentrations of nutrients in water between the dry and rainy seasons. The outflow of water caused by rain carried the material around the pond directly into the water; Conclusions: The system studied was influenced by rain and lack of adequate management of the surrounding area. Water quality was deteriorated by increase in nutrient concentrations, fecal coliforms and reduction of dissolved oxygen in the water during the rainy season. This was due to allochthonous material from the area surrounding the pond that affected negatively the supply system.

Keywords: water quality, fecal coliforms, rainfall, trophic state, aquaculture.

Resumo: Objetivo: O objetivo deste estudo foi avaliar durante as estações seca e estação chuvosa a qualidade da água de um viveiro, coberto por macrófitas, utilizado como sistema de abastecimento de água para aquicultura; Métodos: Foram estabelecidos 6 pontos para a coleta das amostras de água na superfície do viveiro, envolvendo entradas e saídas da água. As coletas foram realizadas mensalmente entre junho de 2008 e maio de 2009; Resultados: Os pontos P₁, P₂ e P₃, devido à entrada de água no viveiro apresentaram maiores concentrações de nutrientes com elevado estado trófico e, a entrada de capivaras nestes locais promoveu a suspensão do sedimento e aumento de coliformes fecais. Há significativas diferenças (p < 0,05) nas concentrações de nutrientes na água entre seca e chuva, com o escoamento de água gerado pela precipitação carreando material do entorno do viveiro para a água; Conclusões: O sistema estudado sofre influência direta da precipitação e da ausência de manejo adequado da área do entorno. Durante a estação chuvosa a qualidade da água ficou comprometida com aumento da concentração de nutrientes, coliformes fecais e redução do oxigênio dissolvido na água, devido ao material alóctone proveniente da área ao redor do viveiro, afetando negativamente o sistema de abastecimento.

Palavras-chave: qualidade de água, coliformes fecais, precipitação, estado trófico, aquicultura.
1. Introduction

Limnological studies are important to understand aquatic environments foregrounding the adequate use of water. They provide knowledge that would produce technologies for water management and guarantee water supply in adequate conditions for aquaculture. Since water resources have significant ecological, economical and social importance, the quality of aquatic ecosystems affects society as a whole (Calijuri et al., 2008).

The protection of water bodies involves three basic aspects: protection of water sources, water treatment and the maintenance of the integrity of the water environments (Plummer and Long, 2007). The main water sources for the maintenance of aquaculture tanks and ponds should not be negatively affected by floods from the surrounding areas (Sipaúba-Tavares et al., 2007).

Cattle-raising activities in areas close to aquaculture systems affect water quality and modify the quantity of nutrients in the water and sediments. They actually indicate the need for riparian vegetation that would effectively protect the environment against runoff water from agricultural areas and pastureland (Meador and Goldstein, 2003). Rainfall and surface water discharge also contribute towards the accumulation of allochthonous material since they carry away substances around the basin and cause changes in the water quality of the receiving water bodies (Neill et al., 2004).

Environments which receive water inflow from agricultural areas have high nutrient levels, high chlorophyll-a rates and great amount of suspended particles (Silva and Sacomani, 2001; Brainwood and Maheshwari, 2004). Eutrophication of water bodies is frequently the outcome of nutrient accumulations from soil (Taguchi and Nakata, 2009) and in spite of great progress in naturalizing the phenomenon, the reversion of the process is still a challenge. The best strategy lies in conservation rather than in the restoration of the environment (Suding et al., 2004).

Certain inconveniences in the case of aquatic plants comprise excessive growth and natural death with a consequent rise in nutrient rates by decomposition. However, proper management provides filtration, absorption and biodegradation and contributes towards an improvement of water quality in eutrophicating environments (Ruggiero et al., 2003; Joniak et al., 2007; Lishawa et al., 2010).

Current analysis evaluates the effect of naturally grown macrophytes in a pond with water supplying a system for the breeding of aquatic organisms. It also determines the effect of the plants on the water quality by comparing water inflow and outflow. Further, it investigates whether the pond may adequately supply water to aquaculture ponds during the dry and rainy seasons.

2. Methods

2.1. Study area and sampling period

Current research was conducted in a pond at the Aquaculture Farm (21° 15' S and 48° 18' W), with continuous flow of water, 3,800 m² area and an approximately 14-day residence time (Sipaúba-Tavares et al., 1991).

The pond receives water directly from several sources and is practically covered with macrophytes, mainly *Salvinia auriculata* Aublet and *Eichhornia azurea* (Sw.) Kunth. The pond had already been used for fish breeding, although some years ago it became a water reservoir to supply the breeding system of water organisms of the Aquaculture Farm. Some fish species, such as *Oreochromis niloticus* (tilapia) and *Astyanax* sp. (lambari), are still extant in the pond and survive by feeding on its aquatic biota (Sipaúba-Tavares, 2006).

Water samples were collected at the surface (0.10 m depth) at six points: *P*₁ = close to the water sources (water inflow from the source and from runoff water); *P*₂-₃ = pond sides and inflow points of runoff water during the rainy season; *P*₄ = the deepest and most central point in the pond; *P*₅-₆ = outflow. Points *P*₁, *P*₂ and *P*₃ are also the inflow points of the capybaras (*Hidrochoerus hydrochaeris*, Linnaeus, 1766) in the supply pond (Figure 1). The climate, according to Köpen’s classification is Cwc (Peel et al., 2007), subtropical, relatively dry during the winter (June to September) and rainy in the summer (December to March), with mean yearly temperature of 22 °C, rainfall 1,424.6 mm and mean altitude 605 m.

2.2. Physical, chemical and microbiological parameters

Samples for abiotic parameters and *Escherichia coli* were undertaken monthly between June 2008 and March 2009. Temperature, electrical conductivity and pH were measured by multiprobe HORIBA U-10 water quality check and dissolved oxygen was determined by oxygen meter YSI-55. Nitrite, nitrate, orthophosphate, total phosphorus and ammonia were determined...
was used to monitoring the trophic level. TSI is the mean obtained from the sum of chlorophyll-a trophic state index (CTSI) and phosphorus trophic state index (PTSI).

2.4. Statistical analysis

The non-parametric Mann-Whitney test (U test) compared physical and chemical parameters and coliform with climatic seasons (dry and rainy season) and points (inflow and outflow). Kruskal-Wallis test was employed to compare sampling points in each season (Siegel, 1975). Results were evaluated by data multivarded analysis. Principal Components Analysis (PCA) was used to reduce the dimensionality of the limnological variables in relation to sampling points (Manly, 1986). Points were grouped by cluster analyses during the dry and rainy seasons to obtain similarity among the six points (Zar, 1999). Co-variance matrix was employed and data were transformed by range

Figure 1. Cross-section of the supply pond under analysis, where: P1 - P6 = sampling points, 1 = cattle-raising section and 2 = sheep-breeding section (adapted from Sipaúba-Tavares et al., 1991).
emphasized that the constant entry of capybaras (*Hydrochoerus hydrochaeris*) at this point increased the ions in the water because of sediment suspension.

Owing to local climatic conditions, water temperature and mean monthly rainfall were higher during the rainy season and scored a significant difference (*p* < 0.05) between the dry and rainy seasons (*Z*).

Inflow points (P<sub>1</sub>, P<sub>2</sub> and P<sub>3</sub>) differed significantly (*p* < 0.05) from the others during the dry season (*Z*), with higher rates in nitrate, fecal coliforms, *E. coli*, chlorophyll-a, BOD<sub>5</sub>, TDS and TSS (Table 1).

There was a significant difference (*p* < 0.05) during the rainy season between the inflow (P<sub>1</sub>, P<sub>2</sub> and P<sub>3</sub>) and outflow (P<sub>5</sub> and P<sub>6</sub>) points (*Z*<sub>2</sub>) for conductivity, nitrate, total phosphorus, orthophosphate, *E. coli*, total coliforms, BOD<sub>5</sub>, TDS and TSS (Table 1), with higher concentrations at the inflow points.

There were significant differences (*p* < 0.05) in temperature, dissolved oxygen, pH, nitrate, nitrite, total phosphorus and orthophosphate during the dry and rainy seasons (*U*). Temperature, pH, concentration of nitrate, nitrite, total phosphorus and orthophosphate water were higher during the rainy season, whereas dissolved oxygen concentration was higher during the dry one (*p* < 0.05) (Table 1).

Significant differences (*p* < 0.05) occurred in nitrate concentrations between P<sub>1</sub> and P<sub>3</sub> during the dry season, with mean concentrations 806.7 µg.L<sup>-1</sup> and 582.9 µg.L<sup>-1</sup> respectively, and between P<sub>3</sub> and P<sub>6</sub> during the rainy season, with mean concentrations 659.3 µg.L<sup>-1</sup> and 498.5 µg.L<sup>-1</sup>. During the dry season, P<sub>1</sub> and P<sub>6</sub> differed in total phosphorus, with mean concentrations 52 µg.L<sup>-1</sup> and 22.7 µg.L<sup>-1</sup>, respectively, whereas during the rainy season

**Figure 2.** Cluster analyses with average physical, chemical and microbiological parameters at sampling points in the pond; D = dry season; R = rainy season.
During the rainy season, significant differences ($p < 0.05$) were observed between $E. coli$ and fecal coliforms at points P3 (24.8 NMP.mL$^{-1}$ and 21.1 NMP.mL$^{-1}$), P5 (0.4 NMP.mL$^{-1}$ and 0.5 NMP.mL$^{-1}$) and P6 (0.5 NMP.mL$^{-1}$ and 0.5 NMP.mL$^{-1}$) (Table 1). No significant difference ($p > 0.05$) was reported for transparency, organic matter and phosphorus in the sediment between seasons and points. P2 had a higher rate in organic matter (23.6%) and P4 had a lower one (9.9%) (Table 1). Total phosphorus differences between P1 and P5 occurred with mean concentrations 66.9 µg.L$^{-1}$ and 38.3 µg.L$^{-1}$ respectively. There was no significant difference for orthophosphate ($p > 0.05$) among the points (Table 1).

Significant differences ($p < 0.05$) were detected during the dry season for $E. coli$ between P1 and P5 and P6 (6.6 NMP.mL$^{-1}$, 0.4 NMP.mL$^{-1}$ and 0.3 NMP.mL$^{-1}$ respectively). In the case of fecal coliforms, P1 (6.8 NMP.mL$^{-1}$) differed ($p < 0.05$) from P6 (0.2 NMP.mL$^{-1}$), whereas P3 (12.3 NMP.mL$^{-1}$) differed ($p < 0.05$) from P5 (0.3 NMP.mL$^{-1}$) and P6 (0.2 NMP.mL$^{-1}$) (Table 1). During the rainy season, significant differences ($p < 0.05$) were observed between $E. coli$ and fecal coliforms at points P3 (24.8 NMP.mL$^{-1}$ and 21.1 NMP.mL$^{-1}$), P5 (0.4 NMP.mL$^{-1}$ and 0.5 NMP.mL$^{-1}$) and P6 (0.5 NMP.mL$^{-1}$ and 0.5 NMP.mL$^{-1}$) (Table 1).

No significant difference ($p > 0.05$) was reported for transparency, organic matter and phosphorus in the sediment between seasons and points. P1 had a higher rate in organic matter (23.6%) and P4 had a lower one (9.9%) (Table 1). Total phosphorus

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**Figure 3.** Interpolation of autovalues from the matrix of abiotic and microbiological parameters in the pond, where a) the first two components, b) the first and third components, D = dry, R = rainy, DO = dissolved oxygen, Rain = rain-fall, Orto = orthophosphate, Cond = conductivity, OMs = organic matter in the sediment, Ps = phosphorus in the sediment, TC = total coliforms, $E. coli$ = *Escherichia coli*, TSS = total suspended solids, TDS = total dissolved solids, Temp = temperature, Clo a = chlorophyll-a, TP = total phosphorus and Transp = transparency.
<table>
<thead>
<tr>
<th>Variables</th>
<th>Dry season</th>
<th>Rainy season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain</td>
<td>18.9 ± 20.7</td>
<td>18.9 ± 20.7</td>
</tr>
<tr>
<td>Temp</td>
<td>20.1 ± 1.1</td>
<td>19.9 ± 1.3</td>
</tr>
<tr>
<td>Cond</td>
<td>45.2 ± 2.8</td>
<td>46.0 ± 3</td>
</tr>
<tr>
<td>pH</td>
<td>7.5 ± 0.4</td>
<td>7.0 ± 0.4</td>
</tr>
<tr>
<td>DO</td>
<td>3.4 ± 0.6</td>
<td>3.5 ± 1.2</td>
</tr>
<tr>
<td>Nitrate</td>
<td>806.7 ± 3</td>
<td>714.2 ± 7</td>
</tr>
<tr>
<td>Ammonia</td>
<td>38.6 ± 19.3</td>
<td>43.7 ± 37.4</td>
</tr>
<tr>
<td>TP</td>
<td>52.0 ± 23.4</td>
<td>35.4 ± 11.4</td>
</tr>
<tr>
<td>Ortho</td>
<td>4.1 ± 6.5</td>
<td>2.2 ± 4.4</td>
</tr>
<tr>
<td>E. coli</td>
<td>6.6 ± 5.6</td>
<td>6.7 ± 6.6</td>
</tr>
<tr>
<td>TC</td>
<td>6.8 ± 5.3</td>
<td>5.1 ± 5.9</td>
</tr>
<tr>
<td>OMsed</td>
<td>17.9 ± 2.6</td>
<td>12.8 ± 4.7</td>
</tr>
<tr>
<td>Psed</td>
<td>0.9 ± 0.2</td>
<td>0.7 ± 0.3</td>
</tr>
<tr>
<td>Chloa</td>
<td>11.2 ± 5.6</td>
<td>11.6 ± 10.8</td>
</tr>
<tr>
<td>Transp</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BOD₅</td>
<td>2.9 ± 0.7</td>
<td>2.2 ± 0.8</td>
</tr>
<tr>
<td>TSS</td>
<td>153.3 ± 127.9</td>
<td>105.0 ± 90.5</td>
</tr>
<tr>
<td>TDS</td>
<td>2441.7 ± 3</td>
<td>3516.7 ± 7</td>
</tr>
</tbody>
</table>

Means and deviation standard of variables analyzed: Rain = Rainfall (mm), Temp = temperature (°C), pH, Cond = conductivity (μS cm⁻¹), Chloa = chlorophyll-a (μg L⁻¹), nitrate, nitrite and ammonia (μg L⁻¹), DO = dissolved oxygen (mg L⁻¹), pH = water pH, ORtO = orthophosphate (μg L⁻¹), TP = total phosphorus (μg L⁻¹), TC = total coliforms (NMP 100 mL⁻¹), E. coli (NMP 100 mL⁻¹), OMsed = organic matter in the sediment (% dry weight), Psed = phosphorus in the sediment (mg g⁻¹), BOD₅ = 5-day biochemical oxygen demand (mg L⁻¹), TDS = total dissolved solids (mg L⁻¹) and TSS = total suspended solids (mg L⁻¹).

Mann-Whitney U-test: Z¹ = comparison between inflow and outflow in dry season (n = 18); Z² = comparison between inflow and outflow in rainy season (n = 18); Z³ = mean comparison between dry season and rainy season (n = 36); Kruskal-Wallis test statistic, points with the same letter do not differ (n = 6); *p < 0.05; **p < 0.01; - = not measured, NS = not significant.
in the sediment had a higher concentration at $P_1$ (0.9 mg·g$^{-1}$) and a lower one at $P_4$ (0.6 mg·g$^{-1}$) (Table 1). Water transparency was higher at $P_4$ (149 cm) and lower at $P_6$ (101 cm) (Table 1).

Chlorophyll-a concentration differed significantly ($p < 0.05$) for $Z^1$ and $Z^2$, which revealed a higher association of phytoplankton due to the inflow of nutrients. Significant difference ($p < 0.05$) was detected between $P_1$ and $P_6$ in the two seasons, with 11.2 µg·L$^{-1}$ and 2.6 µg·L$^{-1}$ in the dry season and 29.3 µg·L$^{-1}$ and 5.3 µg·L$^{-1}$ in the rainy season, with the highest concentrations at $P_1$ (Table 1).

BOD$_5$, TDS and TSS rates were significantly different ($p < 0.05$) for $Z^1$ and $Z^2$ and showed that macrophytes and allochthonous material caused an increase in organic matter within the environment. Significant differences ($p < 0.05$) in BOD$_5$ only occurred between $P_1$ (2.9 mg·L$^{-1}$) and $P_3$ (0.9 mg·L$^{-1}$) during the dry season. With regard to TSS, significant difference ($p < 0.05$) occurred between $P_1$ (153.3 mg·L$^{-1}$), $P_3$ (143.3 mg·L$^{-1}$) and $P_5$ (23.3 mg·L$^{-1}$) during the dry season, and between $P_1$ (253.3) and $P_6$ (30 mg·L$^{-1}$) during the rainy season (Table 1).

4. Discussion

Some factors caused variations among the sampling points and between the dry and rainy seasons. The capybaras affected the rates of suspended material, BOD$_5$ and fecal coliforms in the water, even though rainfall was a determining factor in nutrient concentration, pH and dissolved oxygen in the pond and influenced directly the trophic state.

Distinct conditions between the dry and rainy seasons determined changes in leaves, biomass and survival of macrophytes (Touchette et al., 2010). In current study, rainfall affected the inflow of nutrients into the pond, increased the environmental trophic load and impaired the quality of water supply for the aquaculture system.

Insignificant pH oscillations in water are frequent in small ponds with macrophytes and the presence of sediment and plants determine low rates in dissolved oxygen and electrical conductivity with slight acidification of the water (Crispim et al., 2009). However, in current study rainfall was the main factor that increased pH of the water column.

Mean dissolved oxygen concentration remained below 3.4 mg·L$^{-1}$ during the dry season and 2.5 mg·L$^{-1}$ during the rainy season. This fact has been reported by Takamura et al. (2003), who reported that high macrophyte densities decreased the penetration of light and the inflow of allochthonous material during the rainy season, increased water turbidity and impaired the photosynthesis activities of the phytoplankton.

Aquatic plants are greatly recommended because of their high efficiency in removing coliforms, with the subsequent simplifying and lowering of costs in water treatment (Kacar and Gungor, 2010) and a decrease in risks for public health, as recommended by several international organizations (Agatemor and Okolo, 2007).

Current data demonstrated that local fauna (capybara) influenced the rate of fecal bacteria, in the sediment had a higher concentration at $P_1$ (0.9 mg·g$^{-1}$) and a lower one at $P_4$ (0.6 mg·g$^{-1}$) (Table 1). Water transparency was higher at $P_4$ (149 cm) and lower at $P_6$ (101 cm) (Table 1).

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High rates of Trophic State Index (Table 2) occurred at the inflow area of runoff water. Riparian vegetation did not adequately constrain flooding from the pastureland surrounding the pond. Consequently, an increase in the concentrations of phosphorus and other nutrients occurred, favoring vegetal development, especially at the supereutrophic points $P_1$ and $P_3$ respectively during the dry and rainy seasons. Throughout the experimental period $P_4$ was mesotrophic due to its transitional condition between water inflow and outflow (Table 2).

### Table 2. Trophic state at sampling points ($P_1$-$P_6$) during the dry and rainy seasons.

<table>
<thead>
<tr>
<th>Season</th>
<th>Point</th>
<th>TSI</th>
<th>Season</th>
<th>Point</th>
<th>TSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>$P_1$</td>
<td>Supereutrophic</td>
<td>Rainy</td>
<td>$P_1$</td>
<td>Eutrophic</td>
</tr>
<tr>
<td>$P_2$</td>
<td>Eutrophic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_3$</td>
<td>Eutrophic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_4$</td>
<td>Mesotrophic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_5$</td>
<td>Oligotrophic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_6$</td>
<td>Oligotrophic</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Mean dissolved oxygen concentration remained below 3.4 mg·L$^{-1}$ during the dry season and 2.5 mg·L$^{-1}$ during the rainy season. This fact has been reported by Takamura et al. (2003), who reported that high macrophyte densities decreased the penetration of light and the inflow of allochthonous material during the rainy season, increased water turbidity and impaired the photosynthesis activities of the phytoplankton.

Although fecal bacteria are frequently found in environments with high nutrient concentrations (Wilcock et al., 2011), organic carbon is a determining factor for the development of bacteria in water. Principal components analysis in current study revealed the relationship between fecal coliforms and rainfall, suspended matter, nutrients in the water, organic matter and phosphorus in the sediment.

Aquatic plants are greatly recommended because of their high efficiency in removing coliforms, with the subsequent simplifying and lowering of costs in water treatment (Kacar and Gungor, 2010) and a decrease in risks for public health, as recommended by several international organizations (Agatemor and Okolo, 2007).

Current data demonstrated that local fauna (capybara) influenced the rate of fecal bacteria,
BOD₅ suspended solids and conductivity. The capybaras in the environment under analysis deteriorated the water quality by fecal coliforms and sediment suspensions.

Points P₁, P₂ and P₃ are greatly related to chlorophyll-α, total phosphorus and electrical conductivity in the water, due to the inflow of nutrients, runoff of pastureland near the pond, and to animals that affect sediment suspension in shallow environments. Sediment re-suspension may increase phosphorus rates in the water and enhance the increase of phytoplankton in many aquatic environments (Thomaz et al., 2007).

Although a moderate trophic state in water reservoirs may benefit the aquatic organism populations due to an increase in nutrient availability for phytoplankton and zooplankton communities, it may also be a liability because of the supply of nutrients to the toxic microorganisms in the environment (Takenaka et al., 2006). Current study showed that water outflows would become oligotrophic and mesotrophic if the capybaras and the surrounding area were not properly managed. In fact, the trophic status would increase in points P₅-P₆ in the near future.

Water plants may contribute towards an increase in eutrophication during the decomposition processes (Thomaz and Bini, 2003). Macrophytes in current study became biological filters and improved the environmental conditions of points P₁, P₂ and P₃ at the water inflow in the pond and for the water outflow at P₅-P₆ that supply the several ponds of the aquaculture farm.

The system under analysis is directly influenced by rainfall, local fauna and the lack of adequate management around the pond. Water quality during the dry season was adequate for supply even though the nutrients, fecal coliforms and trophic state index increased during the rainy season and dissolved oxygen concentration decreased because of the high load of allochthonous material from the surrounding area. Water deterioration may affect the production capacity and the quality of organisms of the aquaculture farm. The control of allochthonous material from the cattle-raising (cattle- and sheep-breeding) area introduced into the pond by leaching, the isolation of animals that deteriorate water quality and the maintenance of macrophytes in the pond are recommended.

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