Effects of rainfall on water quality in six sequentially disposed fishponds with continuous water flow

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(With 3 figures)

Abstract

An investigation was carried out during the rainy period in six semi-intensive production fish ponds in which water flowed from one pond to another without undergoing any treatment. Eight sampling sites were assigned at pond outlets during the rainy period (December-February). Lowest and highest physical and chemical parameters of water occurred in pond P_1 (a site near the springs) and in pond P_4 (a critical site that received allochthonous material from the other ponds and also from frog culture ponds), respectively. Pond sequential layout caused concentration of nutrients, chlorophyll-a and conductivity. Seasonal rains increased the water flow in the ponds and, consequently, silted more particles and other dissolved material from one fish pond to another. Silting increased limnological variables from P_3 to P_6. Although results suggest that during the period under analysis, rainfall affected positively the ponds' water quality and since the analyzed systems have been aligned in a sequential layout with constant water flow from fish ponds and parallel tanks without any previous treatment, care has to be taken so that an increase in rain-induced water flow does not have a contrary effect in the fish ponds investigated.

Keywords: water exchange, fishpond, limnology, water quality, rainfall.

Efeito da chuva na qualidade da água em seis viveiros de piscicultura com fluxo contínuo de água em disposição seqüencial

Resumo

O estudo foi efetuado durante o período de chuva (dezembro-fevereiro) em seis viveiros de produção semi-intensiva de peixes, a fim de avaliar o efeito da chuva na qualidade da água de viveiros que apresentam fluxo contínuo de água, a qual é passada de um viveiro para outro sem tratamento prévio. Foram amostrados oito pontos de coleta nas saídas dos viveiros. O viveiro P_1 (próximo à nascente) apresentou as menores concentrações físicas e químicas da água e as maiores no viveiro P_4 (considerado um ponto crítico recebendo material alóctone proveniente de outros viveiros e do escoamento do setor de criação de rãs). A disposição seqüencial dos viveiros estudados promoveu aumento nas concentrações dos nutrientes, clorofila-a e condutividade. As chuvas características desta época do ano aumentaram o fluxo de água nos viveiros e conseqüentemente, carreando material particulado e dissolvido de um viveiro para outro e, promovendo um aumento das variáveis limnológicas em direção do P_3 ao P_6. Os resultados sugerem que a chuva no período de estudo afetou positivamente a qualidade da água dos viveiros estudados, porém, como os sistemas analisados estão dispostos em distribuição seqüencial e escoamento constante da água de viveiros e tanques paralelos sem tratamento prévio, cuidados devem ser averiguados para que o aumento do fluxo de água provocado pelas chuvas não tenha efeito adverso nos viveiros estudados.

Palavras-chave: viveiros, limnologia, qualidade da água, fluxo contínuo, chuva.

1. Introduction

The major source of water for filling and maintaining water levels in ponds are surface runoff from springs affected by rainfall. The availability of water inland aquaculture is closely related to rainfall (Yoo and Boyd, 1994), and an understanding of local rainfall patterns is of paramount importance in pond management (Boyd, 2000).

Since fish culture ponds are very shallow, the continuous flow of water, wind and rainfall often cause water circulation and transform it into a dynamic ecosystem (Sipaúba-Tavares et al., 1994a).

Several factors interfere in fish culture systems, especially management, morphometry and climatology.

This is due to the fact that total rainfall greatly affects the dynamics of the environments, transports nutrients and allochthonous materials, and alters the water's visual, physical and chemical characteristics.

It is a well-known fact that shallow lakes, wetlands and pond systems are almost invariably connected hydraulically to the surrounding unconfined aquifer systems (Furrey and Gupta, 2005).

Several management practices are employed in Brazil in the culture of aquatic organisms, such as tanks and ponds with and without flow, pens and cages. In southeastern Brazil continuous water flow systems are usually built in such a manner that water flows from one pond to another without previous treatment, eventually causing fish mortality or diseases, and, consequently, reducing yield and production.

When water is drained directly from one pond to another, it may affect the characteristics of subsequent fish ponds. Moreover, if ration or other material is added, the next pond may become silted owing to accumulation (Boyd and Queiroz, 2001).

The neutralization of accumulative effects depends on rain intensity and continuous water flow system in the ponds. Since in this case most materials are spilled outside the fish culture system, turbidity increases due to the re-suspension of particles on the pond's shallow sediment and to the decrease in light penetration. Consequently, oxygen production in the water occurs (Boyd, 2001). Rains have two distinct effects on water quality in shallow fish-producing systems: a diluting effect by which excess of nutrients, food remains and other materials in the water diminishes; and an increase in turbidity due to excess of particles from sediments in the water.

Rainfall causes transport of nutrients and particles, such as agricultural residues, salt particles and materials from rivers and streams, by draining water from margins to the ponds and directly affecting the chemical composition of water (Viner, 1975).

Rainfall regimen in shallow systems is a main activity which affects the concentration and distribution of inorganic and dissolved nutrients, heat throughout the water column and suspended materials, and, consequently, transparency and depth (Landa, 1999).

Current analysis evaluates the limnological characteristics of water output in six sequentially aligned continuous water-flow ponds and the effects of rainfall on the water quality of the systems.

2. Material and Methods

2.1. Area and sampling site

Analysis was carried out at the Aquaculture Center (21° 15' S and 48° 18' W) of the Universidade Estadual Paulista (UNESP, Jaboticabal SP Brazil), in six ponds with continuous water flow (Figure 1). The six fishponds (P_1 to P_6) were laid out sequentially, or rather water from one fishpond flowed directly into another, while it received water from other tanks and smaller parallel fishponds used by the nutrition, frog culture, fish breeding and shrimp culture sectors. Fishpond P_4 is the only pond that has another water outlet, that is, water does not flow directly into the subsequent fish pond (Figure 1). Fishponds displayed a surface area ranging between 3,800.31 m^2 (P_1) and 9,230.6 m^2 (P_3), with a mean depth of 1.31 m (Sipaúba-Tavares et al., 1991). Water samples were taken between December 1998 and February 1999 at the outlets, during 20 consecutive days, in each pond. High temperatures and extensive rainfall characterize the period (Sipaúba-Tavares et al., 1991). Eight sampling sites were assigned: two in pond P_1 (S_1 and S_2), one in pond P_2 (S_3), two in pond P_3 (S_4 and S_5), one in pond P_4

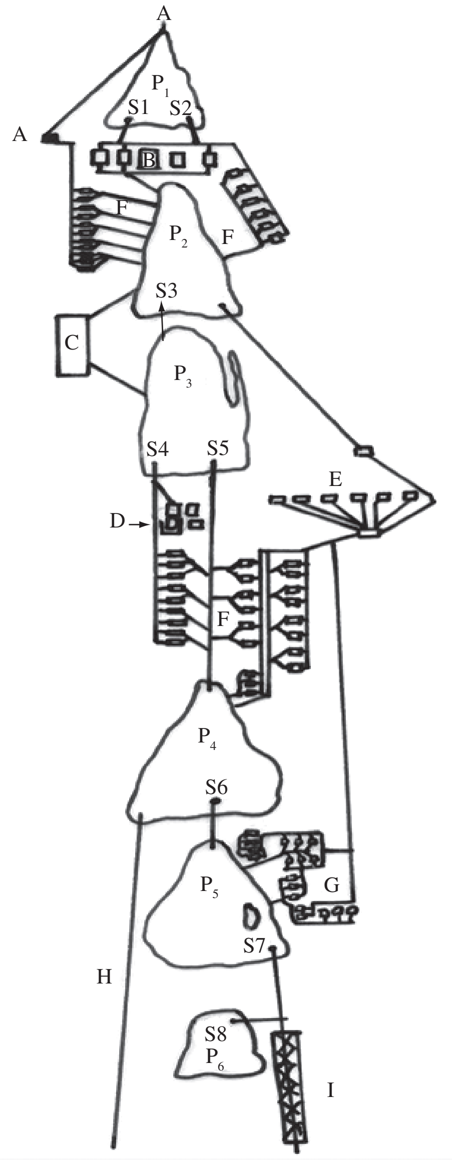

Figure 1. Cross-section of fishponds studied, where: A = springs; B = ornamental fish lab; C = fish nutrition lab; D = pathology lab; E = frog culture; F = fishponds; G = shrimp culture; H = underground water to irrigation; I = wetland; P_1-P_6 = ponds; S_1-S_8 = sampling sites.

(S_6), P_5 (S_7) and P_6 (S_8). Water samples were collected at the surface using a 5 L Van Dorn bottle (Figure 1).

2.2. Physical and chemical parameters

Temperature, pH, dissolved oxygen and conductivity were taken by probe Horiba U-10. Total phosphorus, nitrite, nitrate, and ammonia were determined according to Golterman et al. (1978) and Koroleff (1976). Whereas chlorophyll-a was determined according to Nush (1980), transparency was measured by Secchi disk.

2.3. Climatic factors

Data on daily precipitation, isolation hour numbers, relative air humidity and air temperature were supplied by the Agricultural Climatology Station of the Universidade Estadual Paulista, Jaboticabal, SP, Brazil.

2.4. Statistical analysis

Firstly, limnological variables were analyzed and then the variance homogeneity of the ponds was tested. One-way ANOVA was employed for homogeneous variances (Fowler et al., 1998). When the mean variances were different, the Least Square Differences test – LSD (Sokal and Rohlf, 1981) was employed; in the case of distant variances, Friedman's non-parametric test for K related samples was applied (Siegel, 1975) using the a posteriori mean test. Significance level was $P = 0.05$.

3. Results

Highest chlorophyll-a average (259 $\mu g.L^{-1}$) was reported in pond P_2 at S_3, and the lowest (8 $\mu g.L^{-1}$) in pond P_1 at S_2. In ponds P_3 and P_4, where chlorophyll-a showed over 70 $\mu g.L^{-1}$, concentrations, transparency was below 40 cm (Figure 2). Mean values were different ($P < 0.05$) to chlorophyll-a (Table 1).

Nitrogen compounds had lower concentrations at pond P_1 (S_1 and S_2), with the exception of nitrate, which varied between 47 and 132 $\mu g.L^{-1}$ after day 10. Ammonia was the most abundant nitrogen compound at sites S_5 (pond P_3), S_6 (pond P_4), and S_7 (pond P_5). Differences ($P < 0.05$) in ammonia rates have been reported among the fishponds, with lowest rates in P_1, P_2 and P_3 and highest rates in the last ones (P_4, P_5, and P_6), revealing a slight decrease in P_6. Nitrite was the least abundant and its highest average concentrations (25 $\mu g.L^{-1}$) occurred in ponds P_3 (S_5) (Figure 2). Mean nitrate rates were higher in P_4 and P_5. However, they were similar when compared to rates of P_1, P_2, and P_3. Ponds P_1 to P_4 were similar in nitrite mean rates and lowest in P_5 and P_6 (Tables 1, 2).

Total phosphorus was below 30 $\mu g.L^{-1}$ in pond P_1 (S_1 and S_2) and pond P_6 (S_8); the rate of total phosphorus in the others ponds was higher than above-mentioned values and reached concentrations of 237 $\mu g.L^{-1}$ (S_7) (Figure 2). Differences ($P < 0.05$) for total phosphorus have been reported among ponds, with lowest rates in P_1, P_2, and P_3, and highest rates in P_4 and P_5, with a later decrease in P_6. (Table 1; Figure 2).

Temperature was similar ($P > 0.05$) for all ponds (Tables 1, 3). Ponds P_1, P_2, and P_3 had similar dissolved oxygen averages, but were higher in P_4, P_5 and P_6 (Table 2). Dissolved oxygen concentrations were lowest in pond P_4 (S_6) varying between 1.00 to 3.7 $mg.L^{-1}$, but highest in pond P_1 (S_1 and S_2) with over 4 $mg.L^{-1}$. Maximum dissolved oxygen concentration was reported in pond P_2 (S_2) 7.4 $mg.L^{-1}$ (Table 3).

Water from sites S_1 and S_2 (P_1) was acid owing to direct spring water inlet in P_1, and pH increase in ponds P_3 up to pond P_6. Water was alkaline, ranging from 7.1 to 7.4, only at site S_6 (pond P_4). Differences ($P < 0.05$) in pH mean rates were reported between the ponds (Tables 1, 3).

Water transparency was high at pond P_1, average 84 cm, while the lowest mean values occurred in ponds P_4 with 29 cm. Whereas transparency between ponds varied from 70 cm (P_4) to 84 cm (P_1), it was similar in ponds P_3, P_5, and P_6 ($P < 0.05$) (Tables 1, 2, 3).

Mean conductivity rates were lower in P_1 (S_1 and S_2) and varied between 21 and 24 $\mu S.cm^{-1}$, but higher in P_4, varying between 97 and 118 $\mu S.cm^{-1}$. Rates tended to double as from P_4 ($P < 0.05$) (Tables 1, 3).

Climate during the period under analysis was according to typical regional patterns, with heavy rainfall and high temperatures. Monthly total rainfall variations were 324.7 mm in December; 415.9 mm in January; 375.4 mm

Table 1. Summary of statistical analyses for physical and chemical parameters in studied ponds.

Parameters	Homogeneous variance test	ANOVA	Friedman
pH	Heterogeneous	-	$P < 0.05$
Temperature (°C)	Homogeneous	$P > 0.05$	-
Dissolved Oxygen ($mg.L^{-1}$)	Homogeneous	$P < 0.05$	-
Conductivity ($\mu S.cm^{-1}$)	Heterogeneous	-	$P < 0.05$
Ammonia ($\mu g.L^{-1}$)	Heterogeneous	-	$P < 0.05$
Nitrate ($\mu g.L^{-1}$)	Homogeneous	$P < 0.05$	-
Nitrite ($\mu g.L^{-1}$)	Homogeneous	$P < 0.05$	-
Total Phosphorus ($\mu g.L^{-1}$)	Heterogeneous	-	$P < 0.05$
Chlorophyll-a ($\mu g.L^{-1}$)	Heterogeneous	-	$P < 0.05$
Transparency (cm)	Homogeneous	$P < 0.05$	-

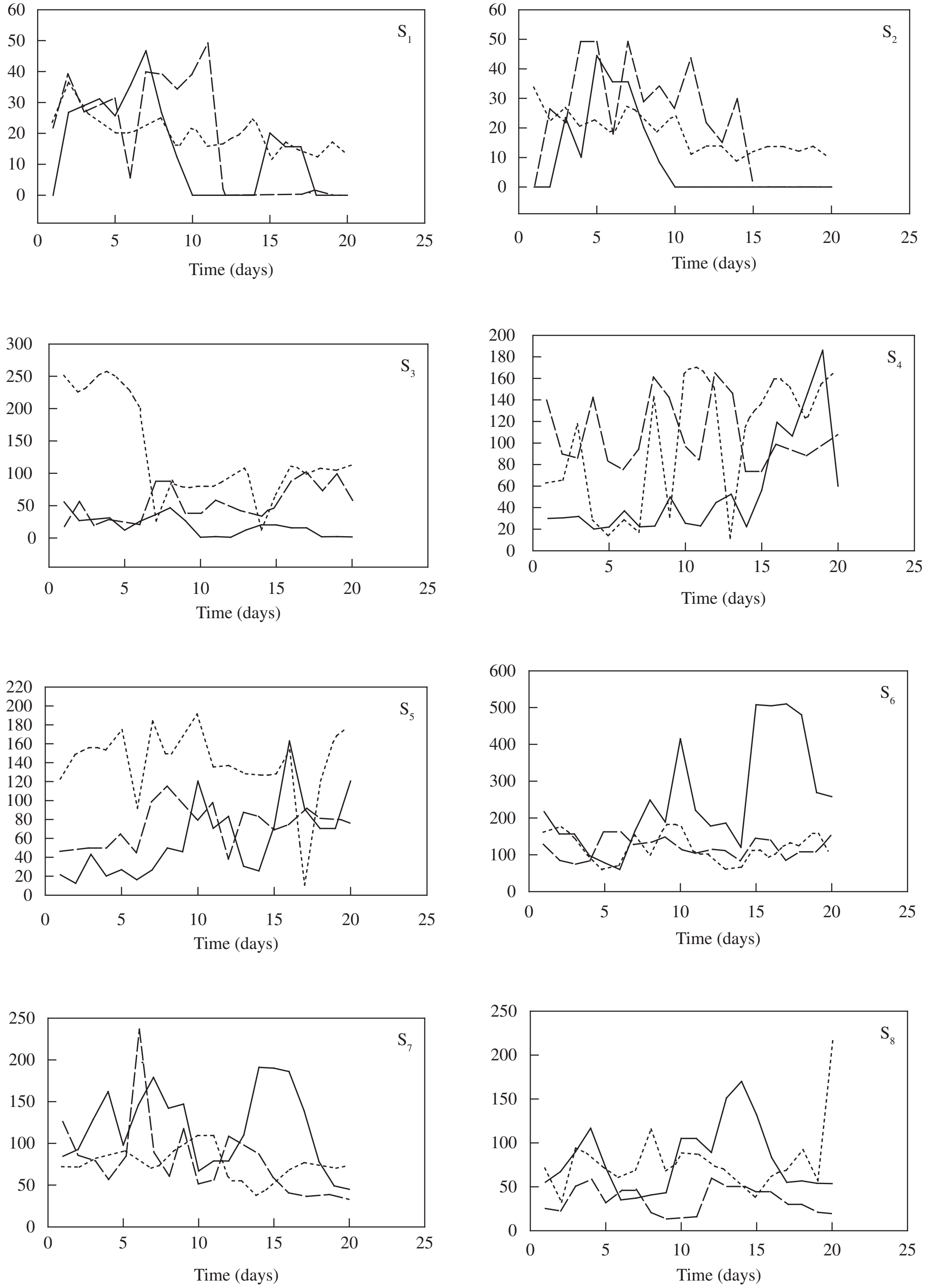

Figure 2. Daily fluctuation (µg.L^{-1}) of chlorophyll-a (…), ammonia (–), and total phosphorus (– –) at the water outlet sites in each pond during the experiment period, where: S_1 and S_2 = pond P_1, S_3 = pond P_2, S_4 and S_5 = pond P_3, S_6 = pond P_4, S_7 = pond P_5, and S_8 = pond P_6.

in February, with highest daily rainfall, 89.5 mm, in February. Air temperature was similar during the whole period, with a monthly variation between 24.2 in February to 24.6 in December. Highest daily sunshine rate was registered in December (12.4 hours) and lowest in February (0.7 hours). Monthly rates of air relative humidity were over 81% in January and February, although in December they were slightly lower, reaching 78.5%. The highest daily air relative humidity rate reached 97.5%, in January, probably due to several rainy days during the month (Figure 3).

4. Discussion

Fishponds with continuous water flow from one pond to another any previous treatment may cause a negative impact on the system during a certain period, such as fish diseases and even mortality, caused by poor water quality.

Table 2. Results from the Least Square Differences (LSD) test for physical and chemical parameters average when variances were homogeneous during the period, (P_1 - P_6 = ponds 1 to 6; continuous line indicates similarities, P > 0.05).

Physicochemical parameters	Relation between average					
Dissolved oxygen	P_1	P_3	P_2	P_6	P_5	P_4
Nitrate	P_6	P_4	P_5	P_1	P_3	P_2
Nitrite	P_5	P_6	P_3	P_4	P_2	P_1
Transparency	P_1	P_2	P_6	P_3	P_5	P_4

Conductivity was high in the ponds P_4, P_5, and P_6, over of 88 μS.cm^{-1}. Sipaúba-Tavares and colleagues (1991, 1994b, 1997) reported values less than 40 μScm^{-1} in fish ponds during this period of the year.

The management of each pond affected directly the water quality. Pond P_1, which receives water directly from springs, actually functions as a water supply for the other ponds. Since no food is added in the water in P_1, there is a trend to oligotrophy, high transparency, dissolved oxygen, and low nutrient contents, with exception of nitrate. According to Muñoz-Carpena et al. (2005), leaching by rainfall is the main mechanism that explains concentrations of nutrient peaks in groundwater. Since P_1 is located near a plantation region with high soil infiltration capacity (Sipaúba-Tavares et al., 1991), fertilizers probably affected the nutrients in the water. However, due to the presence of submersed macrophyte in pond P_1, nutrients in the ponds were directly affected by plant retention of nutrients.

During the period under analysis (high fish production) pond P_2 received daily about 10 to 12 kg of commercial ration, and water from other small ponds, which markedly increased conductivity, total-phosphorus, and chlorophyll-a, with a consequent lower transparency.

Decrease of dissolved oxygen level was reported in pond P_3, because it received water directly from pond P_2, and from approximately 19 small fishponds too. This increased the concentration of allochthonous material in this particular pond, with subsequent high concentrations of chlorophyll-a, total-phosphorus and lower water transparency. There was an increase in ammonia in pond P_3, owing to food management. In fact, pond P_3 is the largest pond and received 20 kg/day of commercial ration during the period.

Highest concentration of ammonia, nitrate, conductivity, chlorophyll-a and decreased concentrations of dissolved oxygen and transparency were observed

Table 3. Minimum, maximum and mean rates (in brackets) of temperature, dissolved oxygen (DO), conductivity, nitrate, nitrite, and transparency in ponds, and results of One-way ANOVA between ponds, (P = ponds, S = sites; P > 0.05 = not significant, P < 0.05 = significant).

Parameters	P1		P2	P3		P4	P5	P6	ANOVA
	S1	S2	S3	S4	S5	S6	S7	S8	
Temperature (°C)	25.5-28.3 (27.0)	25.8-28.3 (28.0)	25.2-28.0 (26.1)	26.5-28.9 (28.0)	26.4-28.9 (28.0)	26.2-28.8 (27.5)	25.1-28.1 (27.0)	25.1-28.5 (27.1)	P > 0.05
DO (mg.L^{-1})	4.1-7.3 (5.0)	4.7-7.4 (6.0)	1.0-6.8 (4.0)	4.2-5.9 (5.0)	3.8-6.4 (5.0)	1.0-3.7 (2.0)	1.0-3.9 (2.2)	1.0-4.6 (2.6)	P < 0.05
Conductivity (μS.cm^{-1})	21-24 (22)	21-23 (22)	49-62 (56)	42-47 (46)	42-48 (46)	97-118 (113)	88-118 (110)	88-103 (98)	P < 0.05
Nitrate (μg.L^{-1})	20.7-132.3 (62.4)	0-109.5 (59.8)	1.0-65.1 (35.3)	8.0-56.5 (38.1)	9.7-68.6 (43.6)	130-234 (182.9)	42.6-292 (181.2)	162-331 (242.0)	P < 0.05
Nitrite (μg.L^{-1})	0.2-3.0 (1.9)	0.6-4.0 (1.7)	1.0-5.7 (3.2)	1.0-7.5 (3.6)	1.4-24.8 (11.1)	1.0-29.8 (4.4)	9.3-20.7 (16.3)	7.8-20.2 (14.9)	P < 0.05
Transparency (cm)	50-100 (84)	70-100 (79)	50-80 (67.5)	30-60 (39)	30-60 (39)	20-50 (31.7)	20-60 (38.3)	30-70 (51.7)	P < 0.05
pH	5.2-6.9 (6.1)	4.6-6.9 (6.0)	5.5-7.1 (6.6)	6.8-7.4 (7.0)	6.6-7.4 (7.0)	7.1-7.4 (7.2)	6.6-7.4 (7.0)	6.9-7.3 (7.0)	P < 0.05

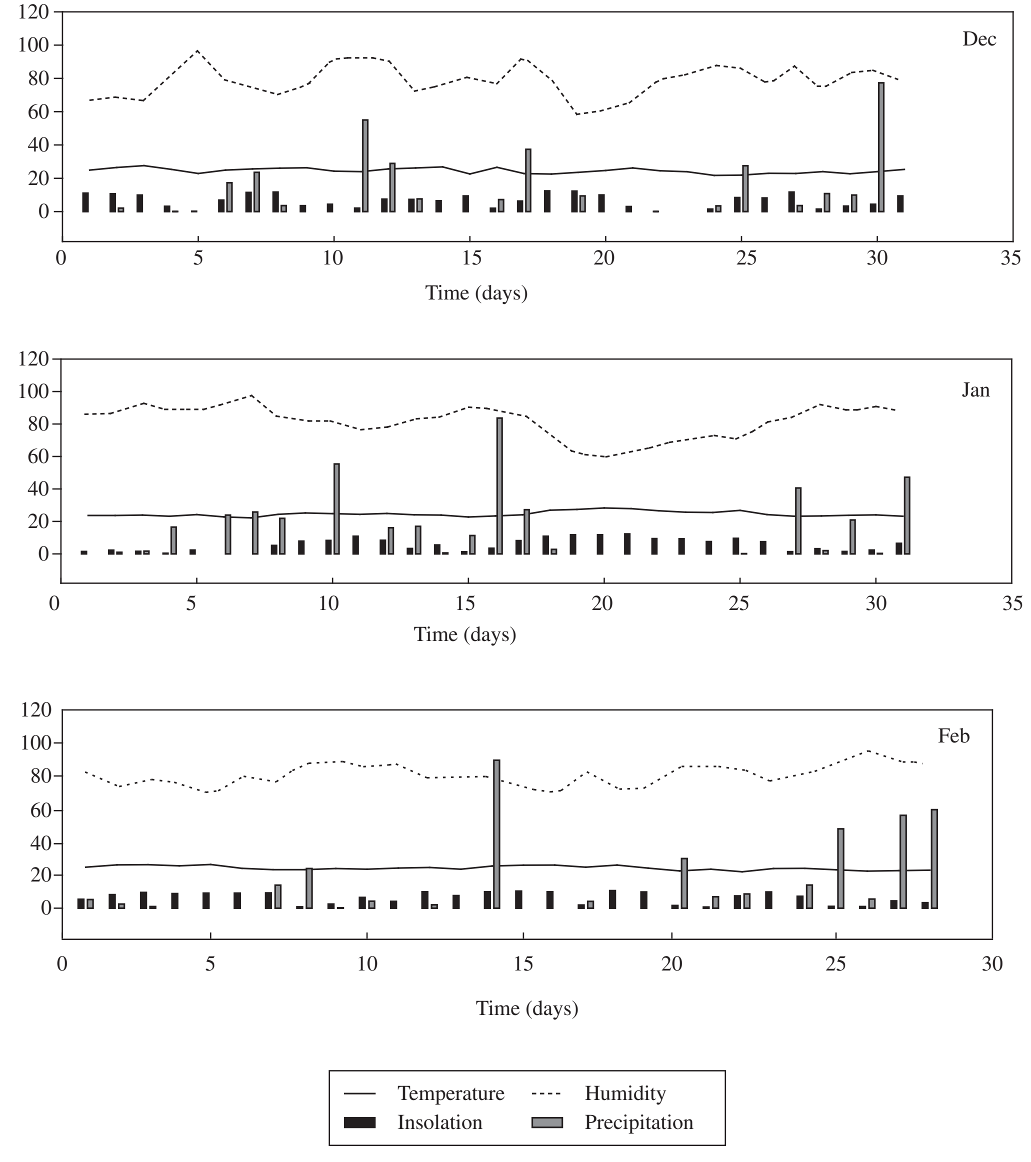

Figure 3. Daily variation of air temperature (°C), air humidity (%), precipitation (mm), and insolation hour numbers (hour) during the experimental period (December–Dec; January–Jan; February–Feb).

in pond P_4. This fact has been associated to water from approximately sixteen 200 m^2-tanks and to organic and inorganic residues from the frog culture, flowing directly into this pond. Consequently, environmental conditions were affected and tended towards an increase in limnological variables with regard to the last three fish ponds. Moreover, approximately 10 to 12 kg of commercial ration (28% of crude protein) was added daily during this period.

Although P_5 and P_6 receive water from all anterior fish ponds, their conditions are better than that of P_4. This is probably due to the fact that the underground water outlet in pond P_4, flowing directly to irrigation, improved water quality in the two subsequent ponds through a reduction of ammonia, total-phosphorus and chlorophyll-a, coupled with a slight increase in dissolved oxygen, nitrate and water transparency. Water in pond P_5 should be treated to minimize the effects of nutrients and organic matter introduced into this pond from shrimp culture.

Any compound in a pond's water brings about changes in water quality which impair the development and the survival of fish. Autochthonous factors, such as biological rates and chemical processes, and external ones, such as rainfall, water flow, insolation, air temperature and wind speed, determine fish culture conditions (Sipaúba-Tavares, 1995).

Insolation rates have an important role in the photosynthesis process and affect pond productivity, due to their smallness and shallowness. Rainfall occurred almost daily during the experimental period and, consequently, insolation was relatively low and relative air humidity was over 60%.

Since rainfall increased the water flow and occasionally caused the ponds to overflow, with an excess of sediment in the water, the pond's limnology was thus directly affected. Since the rain carried away most material in the fishponds, more eutrophized water has been reported in the last three ponds (P_4, P_5, and P_6) when compared to the first three. Further, it should be emphasized that results have been influenced by parallel tanks that overflow into the sequential fish ponds under analysis and contributed with great volumes of organic matter, nutrients and suspended particles. Ponds normally receive great quantities of allochthonous matter, comprising ration, fertilizers and food remains.

The ponds' limnological conditions are proper for fish culture, and rainfall, a characteristic phenomenon during the period of high fish production (extensive supply of ration), has had a positive effect on the fish ponds studied. However, since the systems are sequentially laid out, with a constant overflow of water without any previous treatment of ponds and parallel tanks and with a constant addition of ration, care should be taken so that an increase in rain-induced water flow does not have a contrary effect in the fish ponds investigated.

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