Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1806-2563
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v34i4.12004

Domestic sludge and fish pond effluents in the municipality of Pentecoste, Ceará State, Brazil

Manoel Alves, Rafahel Marques Macedo Fontenele, Davi de Holanda Cavalcante, José Nacélio de Oliveira Segundo and Marcelo Vinícius do Carmo e Sá*

*Laboratório de Ciência e Tecnologia Aquícola, Departamento de Engenharia de Pesca, Centro de Ciências Agrárias, Universidade Federal do Ceará, Campus do Pici, Av. Mister Hull, 2977, 60356-000, Fortaleza, Ceará, Brazil. *Author for correspondence. E-mail: marcelo.sa@ufc.br*

ABSTRACT. The present work aimed to compare the physical and chemical quality of domestic sludge in the city of Pentecoste, State of Ceará, Brazil, to fish pond effluents from the Aquaculture Research Center of the Departamento Nacional de Obras Contras as Secas – DNOCS, located in the same city. The work was carried out in Pentecoste (State of Ceará, Brazil) in three sampling campaigns, with 30-day intervals between them. In each campaign, four samples were collected at different points of the following sites: (1) fish pond supply channel from the Aquaculture Research Center (CPAq) of the DNOCS; (2) fish pond drainage channel of CPAq/DNOCS; (3) tap water from four homes in Pentecoste; and (4) domestic sludge channel of Pentecoste. In the lab, samples were analyzed for dissolved oxygen, total ammonia, free CO_2, nitrite, reactive phosphorus, electric conductivity and chemical oxygen demand (COD), following standard methods. It was concluded that Pentecoste's domestic sludge has a much stronger eutrophication impact on the receiving water than that caused by the CPAq/DNOCS's fish pond effluents.

Keywords: limnology, aquaculture, eutrophication.

Efluentes domésticos e de piscicultura da cidade de Pentecoste, Estado do Ceará, Brasil

RESUMO. A presente pesquisa teve como objetivo comparar a qualidade físico-química de efluentes domésticos da cidade de Pentecoste no Estado do Ceará, com a de viveiros de piscicultura do Centro de Pesquisa em Aquicultura do Departamento Nacional de Obras Contra as Secas – DNOCS, localizado na mesma cidade. O trabalho foi realizado na cidade de Pentecoste, Estado do Ceará, em três campanhas de coletas, com intervalo de 30 dias entre elas. Em cada campanha, foram coletadas quatro amostras em diferentes pontos de cada um dos seguintes locais: (1) canal de abastecimento dos viveiros do Centro de Pesquisas em Aquicultura (CPAq) do DNOCS; (2) canal de drenagem dos viveiros do CPAq/DNOCS; (3) água da torneira de quatro residências localizadas na cidade de Pentecoste e (4) canal de lançamento de esgotos domésticos da cidade de Pentecoste. Em laboratório, as amostras foram analisadas para oxigênio dissolvido, N amoniacal total, CO_2 livre, nitrito, fósforo reativo, condutividade elétrica e demanda química de oxigênio (DQO), de acordo com as respectivas metodologias-padrão. Concluiu-se que os esgotos domésticos da cidade de Pentecoste contribuem mais na eutrofização dos corpos de água receptores que os efluentes de piscicultura do CPAq/DNOCS.

Palavras-chave: limnologia, aquicultura, eutrofização.

Introduction

Water is an essential component to maintenance of life in our planet. Due to water importance for the human populations, several studies were already carried out about the responsible use of that resource (CIRILO, 2008; FERREYRA et al., 2008; PEREIRA-DA-SILVA et al., 2008; RICHTER et al., 2003). The correct management and the rational use of our water bodies can guarantee that asset for future generations. However, the demographic growth and its improper use produce several types of wastewater. As a consequence, the water bodies suffer nowadays a continuous degradation process (HUSSAR; BASTOS, 2008).

The development of urban and industrial areas near to dams, rivers and other water flows increases the degradation of the water bodies. It is estimated that 80% of all diseases and more than 1/3 of the deaths in developing countries, such as in Brazil, have the intake of contaminated water as their main cause (MORAES; JORDÃO, 2002). The problems related to the pollution of water bodies take place when the load of wastes goes beyond the recycling and natural dilution capacity of the receiving waters (FERREIRA et al., 2008).

Currently, the fish culture is helping to increase the feeding security in Brazil. However, the fish culture effluents are nitrogen and phosphorus rich and can cause environmental degradation of the receiving waters (GONÇALVES et al., 2007; GUO et al., 2009). The huge vegetal biomass that can be produced by fish culture is capable to increase enormously the demand for dissolved oxygen in water. Such fact can lead to a complete withdrawal of dissolved oxygen in the aquatic environments and, as an effect, to the occurrence of generalized biota mortalities (CUNHA-SANTINO et al., 2008; MAO et al., 2009).

Beside the aquaculture effluents, there are also other sources of eutrophication to the environment, such as the domestic sludge (YANG et al., 2009). In cities where the sludge treatment system is precarious, such as in the city of Pentecoste, State of Ceará, that problem becomes more critical because almost all human wastes are released directly into its surrounding water bodies. Depending on the rates observed in each case, the environmental impact caused by the domestic sludge can be even worse than that stemmed from the fish culture effluents.

The present study has aimed to compare the physical-chemical quality of the domestic sludge produced by the municipality of Pentecoste, State of Ceará with that originated from the fish culture effluents of the Aquaculture Research Center of the Departamento Nacional de Obras Contra as Secas – DNOCS, located in the same city. Besides, the relative weight of each polluting source in the environmental eutrophication was discussed.

Material and methods

The study was carried out in the city of Pentecoste, State of Ceará, over the months of August, September and October 2010, in three sampling campaigns with a break of 30 days between them. In each campaign four supply waters and wastewater samples were collected at different sites from the following places: (1) the supply channel of the DNOCS's Aquaculture Research Center (CPAq) fish culture ponds; (2) the discharge channel of the CPAq/DNOCS's fish culture ponds; (3) the tap water from four households located in the city of Pentecoste and (4) the municipal sludge discharge channel of the Pentecoste city. The source of water to supply the households of the Pentecoste city is the Pereira de Miranda Reservoir (Pentecoste, Ceará State).

The water samples collections were carried out always in the morning, between 7:30 – 8:30 a.m. The sampling spots used in the subsequent samplings were the same as the previous ones. The water samples were collected with 1 L plastic bottles, identified and stored in one isothermal box.

Soon after the water samplings, the samples were transported to the city of Fortaleza, capital of Ceará State, to the facilities of the Laboratório de Saneamento (Labosan) of the Departamento de Engenharia Hidráulica e Ambiental of the Universidade Federal do Ceará (Fortaleza, Ceará State). In the Labosan, there were carried out the analyses of oxygen chemical demand (COD), through chemical oxidation by the potassium dichromate, as well as the water pH readings (pH-meter Technopon PA 210). Next, the water samples were delivered to the Laboratório de Limnologia (Lablim) of the Fish Engineering Department of the Ceará Federal University. There the water samples were analyzed for dissolved oxygen (DO_2; Winkler's method), total ammonia nitrogen (TAN; Nessler's method), free CO_2 (titration with standard sodium carbonate solution), nitrite (diazoting and azo coupling method), reactive phosphorus (molybdenum blue method) and electrical conductivity (EC; EC meter), according to the respective methodologies presented by APHA (1999). The flow of domestic sludge released by the city of Pentecoste was estimated from the information presented by Von Sperling (2005) and Dias et al. (2010). The information presented by Boyd and Tucker (1998) was used to calculate the rate of effluent releasing of the CPAq/DNOCS's fish culture ponds. The results were analyzed by the one-way ANOVA and the significantly different means were compared two by two by the Tukey's test ($p < 0.05$).

Results and discussion

The pH of the fish culture ponds' supply water was significantly higher than the pH of the tap water, domestic sludge and fish pond effluents. No significant difference was detected between the pH of the tap water, domestic sludge and fish pond effluents (Figure 1). Therefore, there was a significant pH reduction of the fish pond's supply water (affluent) after its use in the fish culture pond and posterior release to the environment (effluent). The domestic sludge and fish pond effluents generally present high concentrations of total suspended solids, especially those of organic origin. Such load of organic matter after bacterial decomposition releases expressive amount of CO_2 to the water. Then, the CO_2 produces carbonic acid after its reaction with the water molecule, causing acidity (CAVALCANTE et al., 2010). The lower pH of tap water in comparison with that from the fish pond affluents can be explained by the chlorination of the municipal supply water. Chlorine after its reaction with the waterborne ammonia produces chloramines (NH_2Cl) that releases, subsequently, H^+ ions to the water (DYCHDALA, 2001).

The average concentration of DO_2 in the domestic sludge was significantly lower than the DO_2 concentrations found in the tap water, fish pond affluents and effluents. The DO_2 concentration in the fish pond effluents was significantly lower than the observed in the fish pond affluents. Both types of effluents, domestic sludge (MOHAN et al., 2010) and fish ponds effluents (DAVIDSON et al., 2008), are characterized by high organic matter concentrations. The decomposing organic matter creates a significant demand for DO_2 in the environment. The reductions in the DO_2 concentrations of the domestic sludge and fish pond effluents, when compared to those for the tap water and fish pond affluents, respectively, demonstrate that fact. The higher DO_2 concentration reduction in the domestic sludge, in relation to the fish pond effluents, suggests that the load of organic matter in the former effluent was significantly greater than in the latter. That supposition is supported by the present work's COD results (Figure 2).

The free CO_2 concentration in the domestic sludge was significantly higher than in tap water and fish pond affluents and effluents. As said previously, the higher concentration of CO_2 in the sludge in comparison to the fish pond effluents indicates a greater organic matter concentration in the first wastewater. The results of COD have showed that the average concentration of organic matter in the domestic sludge was six fold the concentration observed in fish pond effluents. Excessive CO_2 in water makes the gas exchange by fish more difficult, causing respiratory stress to them (DANLEY et al., 2005). The concentration of free CO_2 in the fish pond effluents was significantly higher than for the tap water and fish pond affluents (Figure 1). The concentration of TAN in the domestic sludge was significantly higher than in the fish pond affluents and effluents, and than in tap water. In domestic sludge, as well as in fish pond effluents, their main particulate matter is organic, especially protein. The bacterial decomposition of the protein releases TAN to the water. Ammonia is a toxic compound to aquatic animals and can lead them to death when found in high concentrations in water (MEINELT et al., 2010). The concentrations of TAN in fish pond affluents and effluents were significantly higher than in tap water. The concentration of TAN in the fish pond effluents was significantly higher than in fish pond affluents (Figure 1).

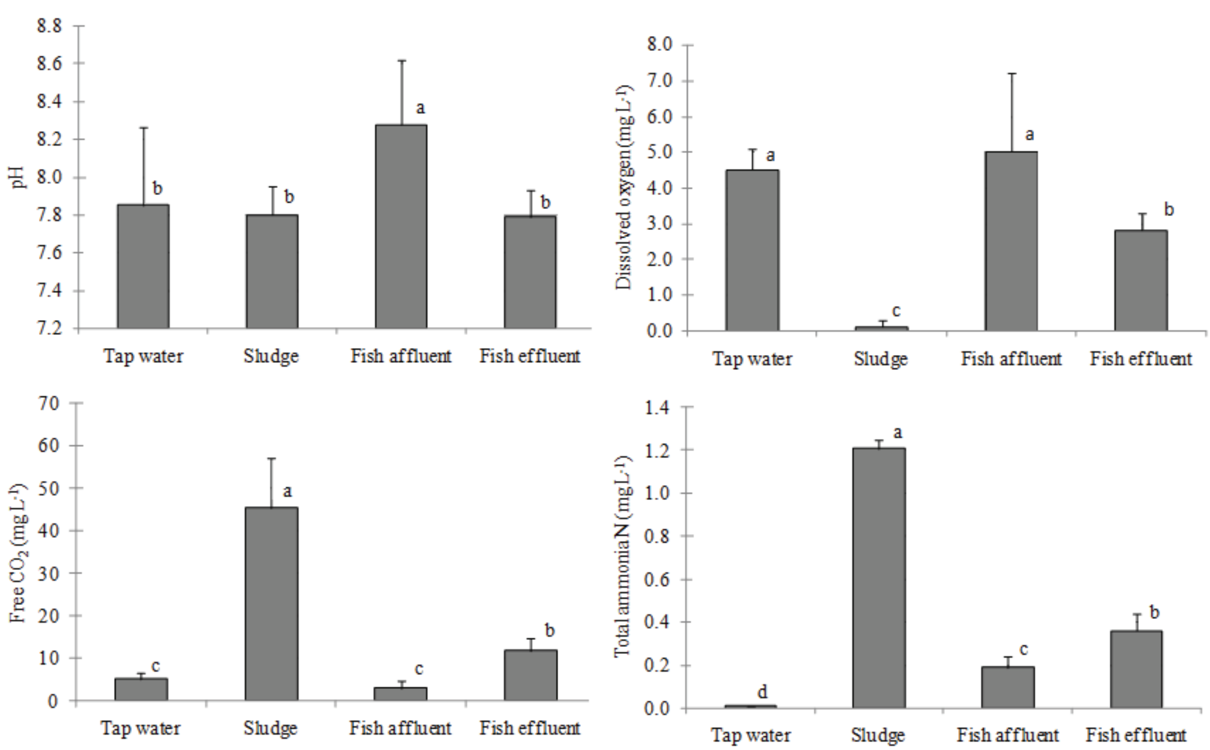

Figure 1. Average values ± standard-deviation of pH, dissolved oxygen, free CO_2 and total ammonia nitrogen (mg L^{-1}) of tap water, domestic sludge, fish pond affluents and effluents. Columns with distinct letters are significantly different between themselves by the Tukey's test ($p < 0.05$).

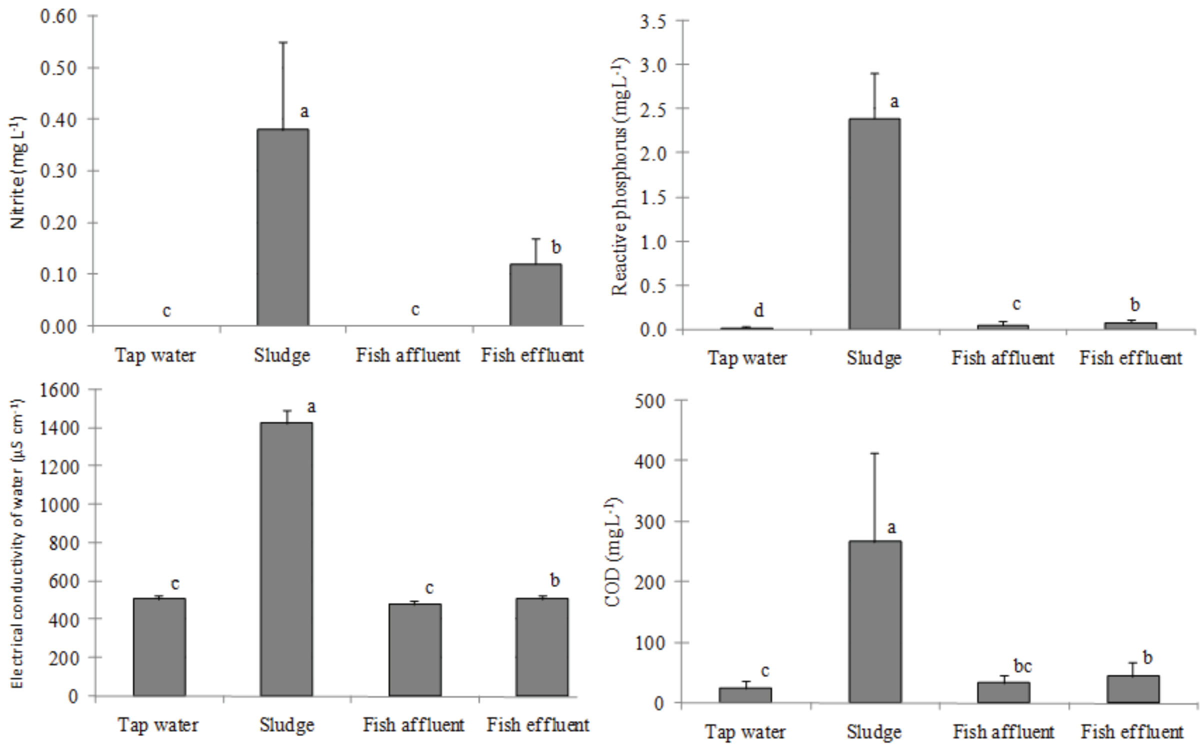

Figure 2. Average values ± standard-deviation of nitrite, reactive phosphorus, electrical conductivity and chemical oxygen demand (COD) of tap water, domestic sludge, fish pond affluents and effluents. Columns with distinct letters are significantly different between themselves by the Tukey's test ($p < 0.05$).

The nitrite concentration of the domestic sludge was significantly higher than that for the fish pond effluents, as well as for the tap water and fish pond affluents. The nitrite concentration of the fish pond effluents was significantly greater than that of the fish pond affluent. No significant difference was observed between the nitrite concentration of the tap water and that for the fish pond affluents (Figure 2). Nitrite accumulates in water when the nitrification process does not complete itself. That happens generally when the DO_2 concentrations in water are low. The domestic sludge, therefore, presents the proper characteristics to develop high nitrite concentrations in water: high ammonia and low DO_2. After nitrite absorption through fish gills it reacts with the hemoglobin iron in the blood, converting it in methaemoglobin which is not capable to transport oxygen. In that case, fish can die suffocated depending on the time of exposition and the concentration of nitrite in the water (WANG et al., 2006).

The concentration of reactive phosphorus in the domestic sludge was significantly higher than in the tap water and fish pond affluents and effluents. The reactive phosphorus concentration in the fish pond effluents was significantly higher than in the fish pond affluents. The concentration of reactive phosphorus of the fish pond affluents was significantly higher than that observed for the tap water (Figure 2). The domestic sludge has expressive amounts of phosphorus from detergent origin (HOUHOU et al., 2009). Besides, the human fecal matter also contains significant phosphorus. In the inland aquatic environments, the load of phosphorus generally results in intense algal blooms. The great biomass produced increases considerably the biochemical demand for oxygen and can, as a consequence, turns the environment to anoxic.

The electrical conductivity (EC) of the domestic sludge was significantly higher than those results observed for the fish pond affluents and effluents, as well as for the tap water. The EC result of the fish pond effluents was significantly higher than the value found for the fish pond affluents (Figure 2). The water's EC can be used as an indirect indicator of eutrophication. Waters with high concentrations of nutrients have higher EC values than those observed in oligotrophic and mesotrophic waters (AKKOYUNLU; AKINER 2012). The increased EC for the domestic sludge supports the present work's results of TAN and phosphorus, and demonstrates the high eutrophication power of that wastewater.

The chemical oxygen demand (COD) of the domestic sludge was significantly higher than those obtained for the other samples (tap water, fish pond affluents and effluents). No significant difference was detected between the COD results of the fish pond affluents and effluents. COD indicates indirectly the concentrations of organic matter and of susceptible chemical-oxidation compounds in water. Maximum COD levels for wastewaters are defined by state laws which aim to protect the environment. The states of Minas Gerais and Rio de Janeiro, for example, have established that 250 mg L^{-1} is the maximum COD level allowed in effluents released to receiving waters. In the State of Ceará, the Superintendência Estadual do Meio Ambiente – Semace have established 200 mg L^{-1} as the maximum COD level of the liquid effluents produced by any polluting source (SEMACE, 2002). The domestic sludges are characterized by high levels of organic matter in relatively low volume of water. That explains the increased COD results of the sludge that were observed in the present work, some close to 500 mg L^{-1}.

In the present work, the nitrite concentration of the fish pond effluents has showed the greatest variation in relation to the values observed in the fish pond affluents. The nitrite concentration in the fish pond effluents was more than 1,000% higher than that in the fish pond affluents (Table 1). Nevertheless, the average nitrite concentration in the fish pond effluents is still below the critical limit from which fish may suffer toxicity (0.3 mg L^{-1}; BOYD; TUCKER, 1998). Even the highest nitrite concentration observed in the present work for the fish pond effluents water samples (0.17 mg L^{-1}) is still below that critical limit. Therefore, although there has been a great increase in the nitrite concentration in fish pond effluents, when compared to the fish pond affluents, nitrite will be released to the receiving waters with probable no considerable damage to the aquatic animals. On the other hand, there would be an increase in the eutrophication of the receiving water depending on the flow of the effluents released to the environment.

After nitrite, the next water quality variable with the highest variation between the fish pond affluents and effluents was the concentration of CO_2. The fish pond effluents have presented almost 300% more free CO_2 than the found in the fish pond affluents. The average concentration of free CO_2 in the fish pond effluents (11.8 ± 3.1 mg L^{-1}) is a little above the safe limit for fish culture (10 mg L^{-1}; BOYD; TUCKER, 1998). However, it is improbable that that level of CO_2 has caused a considerable negative impact on receiving waters, considering the reduced flow of the CPAq/DNOCS's fish pond effluents as showed next.

Only the pH and, especially, the DO_2 concentration of water have presented negative variations between the fish pond effluents and affluents. The aerobic decomposition of the organic matter in the pond (dead plankton, animal feces and non-fed ration) reduces the concentrations of DO_2 in water in direct proportion with the degree of organic load (BRUNE et al., 2003). The average concentration of DO_2 observed in the fish pond effluents (2.8 mg L^{-1}) is capable to negatively impact the environment if the fish pond effluent flow is very high. Therefore, the effects of the fish pond effluent release on the environment will depend on the water and effluent managements effectively employed by the producer. The daily rate of water exchange, the way the ponds are drained (total or partial), and the waste management adopted (direct release to the environment, use of a sedimentation basin, wetland etc.), will define the degree of the fish pond effluent impact on the environment.

The characteristics of the fish pond effluents analyzed in the present work are in agreement with the current technical recommendations for pH and concentrations of TAN, phosphorus and COD (LIN et al., 2010). Those results suggest that the fish culture in the CPAq/DNOCS is carried out according to correct management procedures, especially in regards to the fish stocking densities (carrying capacity) and feed management.

Table 1. Average values ± standard-deviation of electrical conductivity, pH, dissolved oxygen, free CO_2, total ammonia nitrogen, nitrite and reactive phosphorus of the fish pond affluents and effluents.

Variable	Fish pond		Variation (%)	Recommendation for fish pond effluents[1]
	Affluent	Effluent		
pH	8.3 ± 0.3	7.8 ± 0.1	- 5.9	6 - 9
DO_2 (mg L^{-1})	5.0 ± 2.2	2.8 ± 0.5	- 44.0	-
Free CO_2 (mg L^{-1})	3.0 ± 2.0	11.8 ± 3.1	+ 293.3	-
Total ammonia nitrogen (mg L^{-1})	0.19 ± 0.05	0.36 ± 0.08	+ 89.5	< 3.0
Nitrite (mg L^{-1})	0.01 ± 0.00	0.12 ± 0.05	+ 1100	-
Reactive phosphorus (mg L^{-1})	0.05 ± 0.04	0.08 ± 0.03	+ 60.0	< 0.3
Electrical conductivity ($\mu S\ cm^{-1}$)	479 ± 25	510 ± 20	+ 6.5	-
COD (mg L^{-1})[2]	33.6 ± 14	44.9 ± 23	+ 33.6	< 100

[1]Lin et al. (2010). The recommendation of <0.3 mg L^{-1} for phosphorus concentration is for total phosphorus; [2]Chemical oxygen demand.

In the present work, the domestic sludge has presented concentrations of nutrients (N and P) and organic matter (COD) well above the values observed in the fish pond effluents. The greatest variation was observed for reactive phosphorus which was almost 3,000% higher in domestic sludge when compared to fish pond effluents. Next, there are the results of COD which were almost 500% higher than in the fish pond effluents (Table 2).

The DO_2 concentration in the domestic sludge was very close to zero. Therefore, if an equal flow is considered for both types of effluents, domestic sludge and fish pond, the first effluent would have a stronger negative impact on the environment than that caused by the last. However, while the domestic sludge is characterized by high concentrations of pollutants and a low flow, the fish pond effluents present inverse characteristics, that is, diluted concentrations of pollutants and a high flow (BOYD, 2003). Hence, the final effect of the effluent on the receiving waters will depend on the combination of these two factors: pollutant concentrations and effluent flow.

Table 2. Average values ± standard-deviation of the electrical conductivity, pH, dissolved oxygen, free CO_2, total ammonia nitrogen, nitrite and reactive phosphorus of the fish pond effluents and domestic sludge.

Variable	Effluent		Variation
	Fish pond	Domestic	(%)
pH	7.8 ± 0.1	7.8 ± 0.1	-
DO_2 (mg L^{-1})	2.8 ± 0.5	0.1 ± 0.2	- 96.4
Free CO_2 (mg L^{-1})	11.8 ± 3.1	45.4 ± 11.9	+ 284.7
Total ammonia nitrogen (mg L^{-1})	0.36 ± 0.08	1.21 ± 0.04	+ 236.1
Nitrite (mg L^{-1})	0.12 ± 0.05	0.38 ± 0.17	+ 216.7
Reactive phosphorus (mg L^{-1})	0.08 ± 0.03	2.39 ± 0.52	+ 2887
Electrical conductivity (μS cm^{-1})	510 ± 20	1425 ± 71	+ 179.4
COD (mg L^{-1})[1]	44.9 ± 23	267.4 ± 146	+ 495.5

[1]Chemical oxygen demand.

The city of Pentecoste, State of Ceará (Brazil), has almost 34,000 habitants (PMP, 2010). Taking into account that the water intake by habitant per day ranges between 110 – 180 L for small cities, with 10,000 – 50,000 habitants (VON SPERLING, 2005), and the volume of domestic sludge produced per house is approximately equal to the volume of water consumed per house (DIAS et al., 2010), it is estimated that the population of Pentecoste produces between 3,740 and 6,120 m^3 of sludge day^{-1}. At Pentecoste, almost all domestic sludge currently produced is not treated, being released directly to the environment.

Generally, five to ten percent of the total fish pond volume is exchanged daily. Besides, there is a technical recommendation to drain totally the fish pond at the end of the production cycle, or periodically to restore its bottom quality (BOYD; TUCKER, 1998). If we consider one 1-ha fish pond with a average depth of 1 m (total volume = 10,000 m^3) and a production cycle of four months, we will have the releasing of 60,000 – 120,000 m^3 of effluents to the environment, from the daily water exchanges, and 10,000 m^3 from the final harvest drainage. Therefore, there would be a total releasing of 70,000 – 130,000 m^3 of fish pond effluents in four months of fish culture or 538 – 1,083 m^3 ha^{-1} day^{-1}.

In the previous scenario, when it is compared the production of the domestic effluents by the city of Pentecoste (3,740 – 6,120 m^3 day^{-1}) with that from the fish pond effluents (583 – 1,083 m^3 ha^{-1} day^{-1}), it is noted that just 3.4 – 10.5 ha of fish ponds will produce the same level effluents than those from the domestic effluents. However, it is important to consider not only the effluent flow but also the pollutant concentrations in each type of effluent. In the present work, the average concentration of reactive phosphorus in the domestic sludge (2.39 ± 0.52 mg L^{-1}) was 30 times higher that that observed for the fish pond effluents (0.08 ± 0.03 mg L^{-1}). Therefore, it would be necessary the activity of 102 – 315 ha of fish ponds to reach the same level of phosphorus release to the environment of the Pentecoste city's domestic sludge. However, the Aquaculture Research Center (CPAq) of the DNOCS at Pentecoste has only 3.36 ha of fish ponds (8 ponds of 20 x 90 m and 48 ponds of 10 x 40 m), or just 1.1 – 3.3% of the necessary area to cause an eutrophication impact equivalent to that provoked by the domestic sludge.

Conclusion

The domestic sludge of the city of Pentecoste (State of Ceará, Brazil) contributes significantly more to the eutrophication of the receiving Pentecoste's waters than the fish pond effluents from the CPAq/DNOCS. On average, the effect of the CPAq/DNOCS's fish pond effluents on the environmental degradation corresponds to only 2.2% of the effect caused by the domestic sludge, having the release of phosphorus to the environmental as reference.

Acknowledgements

The present work's authors would like to express their gratitude to Pedro Eymard Campos Mesquita and Maria do Socorro Chacon de Mesquita, of the Aquaculture Research Center of the Departamento Nacional de Obras Contra as Secas (CPAq/DNOCS, Pentecoste, Ceará State) for their support over the water samplings performed at the CPAq/DNOCS.

References

AKKOYUNLU, A.; AKINER, M. E. Pollution evaluation in streams using water quality indices: a case study's from Tukey's Sapanca Lake basin. **Ecological Indicators**, v. 18, p. 201-211, 2012.

APHA-American Public Health Association. **Standard methods for the examination of water and waste water**. 20th ed. Washington, D.C.: APHA, 1999.

BOYD, C. E.; TUCKER, C. S. **Pond aquaculture water quality management**. New York: Springer, 1998.

BOYD, C. E. Guidelines for aquaculture effluent management at the farm-level. **Aquaculture**, v. 226, n. 1-4, p. 101-112, 2003.

BRUNE, D. E.; SCHWARTZ, G.; EVERSOLE, A. G.; COLLIER, J. A.; SCHWEDLER, T. E. Intensification of pond aquaculture and high rate photosynthetic systems. **Aquacultural Engineering**, v. 28, n. 1-2, p. 65-86, 2003.

CAVALCANTE, D. H.; BARROS, R. L.; SÁ, M. V. C. Growth performance of Nile tilapia, *Oreochromis niloticus*, fingerlings reared in Na_2CO_3 limed waters. **Acta Scientiarum. Animal Sciences**, v. 32, n. 3, p. 331-336, 2010.

CIRILO, J. A. Políticas públicas de recursos hídricos para o semi-árido. **Estudos Avançados**, v. 22, n. 63, p. 61-82, 2008.

CUNHA-SANTINO, M. B.; GOUVÊA, S. P.; BIANCHINI JR., I.; VIEIRA, A. A. H. Oxygen uptake during mineralization of photosynthesized carbon from phytoplankton of the Barra Bonita Reservoir: a mesocosm study. **Brazilian Journal of Biology**, v. 68, n. 1, p. 115-122, 2008.

DANLEY, M. L.; KENNEY, P. B.; MAZIK, P. M.; KISER, R.; HANKINS, J. A. Effects of carbon dioxide exposure on intensively cultured rainbow trout *Oncorhynchus mykiss*: physiological responses and fillet attributes. **Journal of the World Aquaculture Society**, v. 36, n. 3, p. 249-261, 2005.

DAVIDSON, J.; HELWIG, N.; SUMMERFELT, S. T. Fluidized sand biofilters used to remove ammonia, biochemical oxygen demand, total coliform bacteria, and suspended solids from an intensive aquaculture effluent. **Aquacultural Engineering**, v. 39, n. 1, p. 6-15, 2008.

DIAS, D. M.; MARTINEZ, C. B.; LIBÂNIO, M. Avaliação do impacto da variação da renda no consumo domiciliar de água. **Engenharia Sanitária e Ambiental**, v. 15, n. 2, p. 155-166, 2010.

DYCHDALA, G. R. Chlorine and chlorine compounds. In: BLOCH, S. S. (Ed.). **Disinfection, sterilization and preservation**. 5th ed. Philadelfia: Lea and Febiger, 2001. p. 135-157.

FERREIRA, M. I. P.; FERREIRA-DA-SILVA, J. A.; PINHEIRO, M. R. C. Recursos hídricos: água no mundo, no Brasil e no Estado do Rio de Janeiro. **Boletim do Observatório Ambiental Alberto Ribeiro Lamego**, v. 2, n. 2, p. 29-36, 2008.

FERREYRA, C.; LOË, R. C.; KREUTZWISER, R. D. Imagined communities, contested watersheds: challenges to integrated water resources management in agricultural areas. **Journal of Rural Studies**, v. 24, n. 3, p. 304-321, 2008.

GONÇALVES, G. S.; PEZZATO, L. E.; PADILHA, P. M.; BARROS, M. M. Disponibilidade aparente do fósforo em alimentos vegetais e suplementação da enzima fitase para tilápia-do-nilo. **Revista Brasileira de Zootecnia**, v. 36, n. 5, p. 1473-1480, 2007.

GUO, L.; LI, Z.; XIE, P.; NI, L. Assessment effects of cage culture on nitrogen and phosphorus dynamics in relation to fallowing in a shallow lake in China. **Aquaculture International**, v. 17, n. 3, p. 229-241, 2009.

HOUHOU, J.; LARTIGES, B. S.; HOFMANN, A.; FRAPPIER, G.; GHANBAJA, J.; TEMGOUA, A. Phosphate dynamics in an urban sewer: A case study of Nancy, France. **Water Research**, v. 43, n. 4, p. 1088-1100, 2009.

HUSSAR, G. J.; BASTOS, C. M. Tratamento de efluente de piscicultura com macrófitas aquáticas flutuantes. **Engenharia Ambiental**, v. 5, n. 3, p. 274-285, 2008.

LIN, Y. F.; JING, S. R.; LEE, D. Y.; CHANG, Y. F.; SUI, H. Y. Constructed wetlands for water pollution management of aquaculture farms conducting earthen pond culture. **Water Environment Research**, v. 82, n. 8, p. 759-768, 2010.

MAO, J. Q.; LEE, J. H. W.; CHOI, K. W. The extended Kalman filter for forecast of algal bloom dynamics. **Water Research**, v. 43, n. 17, p. 4214-4224, 2009.

MEINELT, T.; KROUPOVA, H.; STÜBER, A.; RENNERT, B.; WIENKE, A.; STEINBERG, C. E. W. Can dissolved aquatic humic substances reduce the toxicity of ammonia and nitrite in recirculating aquaculture systems? **Aquaculture**, v. 306, n. 1-4, p. 378-383, 2010.

MOHAN, S. V.; MOHANAKRISHNA, G.; CHIRANJEEVI, P.; PERI, D.; SARMA, P. N. Ecologically engineered system (EES) designed to integrate floating, emergent and submerged macrophytes for the treatment of domestic sewage and acid rich fermented-distillery wastewater: Evaluation of long term performance. **Bioresource Technology**, v. 101, n. 10, p. 3363-3370, 2010.

MORAES, D. S. L.; JORDÃO, B. Q. Degradação de recursos hídricos e seus efeitos sobre a saúde humana. **Revista de Saúde Pública**, v. 36, n. 3, p. 370-374, 2002.

PEREIRA-DA-SILVA, W. T.; MARIA-DA-SILVA, L.; CHICHORRO, J. F. Gestão de recursos hídricos: perspectivas do consumo per capita de água em Cuiabá. **Engenharia Sanitária e Ambiental**, v. 13, n. 1, p. 8-14, 2008.

PMP-Prefeitura Municipal de Pentecoste. **Conheça o município** – Dados gerais. Available from:<http://www.pentecoste.ce.gov.br/>. Access on: Nov. 12, 2010.

RICHTER, B. D.; MATHEWS, R.; HARRISON, D. L.; WIGINGTON, R. Ecologically sustainable water management: managing river flows for ecological integrity. **Ecological Applications**, v. 13, n. 1, p. 206-224, 2003.

SEMACE- Superintendência Estadual do Meio Ambiente. **Padrões e condições para lançamento de efluentes líquidos gerados por fontes poluidoras**. Portaria n. 154, de 22 de julho de 2002, publicado no Diário Oficial do Estado, 1 de Outubro de 2002.

VON SPERLING, M. **Introdução à qualidade das águas e ao tratamento de esgoto**. 3. ed. Belo Horizonte: Departamento de Engenharia Sanitária e Ambiental - Universidade Federal de Minas Gerais, 2005.

WANG, Y.; ZHANG, W.; LI, W.; XU, Z. Acute toxicity of nitrite on tilapia (*Oreochromis niloticus*) at different external chloride concentrations. **Fish Physiology and Biochemistry**, v. 32, n. 1, p. 49-54, 2006.

YANG, L.; CHENG, S.; WU, Z. Anthropogenic organic contaminants in water and surface sediments of large shallow eutrophic Chaohu Lake, China. **Fresenius Environmental Bulletin**, v. 18, n. 11, p. 2048-2054, 2009.

Received on December 16, 2010.
Accepted on June 6, 2011.