http://dx.doi.org/10.1590/1519-6984.01016 Original Article

Aquatic life protection index of an urban river Bacanga basin in northern Brazil, São Luís - MA

A. K. Duarte-dos-Santos[a], M. V. J. Cutrim[a], F. S. Ferreira[a], R. Luvizotto-Santos[a], A. C. G. Azevedo-Cutrim[b], B. O. Araújo[a], A. L. L. Oliveira[a], J. A. Furtado[a] and S. C. D. Diniz[a]*

[a]Laboratório de Ficologia – LABFIC, Departamento de Oceanografia e Limnologia – DEOLI, Universidade Federal do Maranhão – UFMA, Av. dos Portugueses, 1966, Bacanga, CEP 65080-805, São Luís, MA, Brazil

[b]Laboratório de Biologia Vegetal e Marinha – LBVM, Departamento de Química e Biologia – DQB, Universidade Estadual do Maranhão – UEMA, Cidade Universitária Paulo VI, s/n, Tirirical, CEP 65055-000, São Luís, MA, Brazil

*e-mail: cutrim@ufma.br

Received: January 13, 2016 – Accepted: April 11, 2016 – Distributed: August 31, 2017
(With 12 figures)

Abstract

Bacanga River Basin faces environmental problems related to urbanization and discharge of untreated domestic sewage, which compromise its ecosystem health. Due to the small number of studies that assessed its water quality, the present study aimed to assess the current status of this ecosystem based on the aquatic life protection index. Samples were carried out every two months, in a total of six events, in six sites along the basin, where the water samples were collected to assess physicochemical parameters and calculate the trophic state index and the index of minimum parameters for the protection of aquatic communities. The data were also compared with values determined by the resolution National Environment Council - CONAMA 357/05. Our results reveal significant changes in the water quality of Bacanga River Basin. An increase in nutrients and chlorophyll-a concentration led it to eutrophication. The surfactant values were high and put in danger the aquatic biota. Dissolved oxygen rates were below the values allowed by the resolution in most sites sampled. The current water quality is terrible for the protection of aquatic life in 61.92% of the sites sampled.

Keywords: water quality, contamination, domestic sewage.

Índice de proteção da vida aquática em uma bacia urbana do rio Bacanga no norte do Brasil, São Luís - MA

Resumo

A Bacia Hidrográfica do rio Bacanga (BHRB) apresenta problemas ambientais relacionados a urbanização e lançamentos de esgoto *in natura* que comprometem a qualidade desse ecossistema. Devido ao reduzido número de estudos associados à avaliação da qualidade da água no local, este estudo teve como objetivo avaliar a situação atual desse ecossistema por meio do Índice de Proteção da Vida Aquática. Seis amostragens bimestrais foram realizadas em seis pontos ao longo da bacia, coletando parâmetros físico-químicos para a aplicação do Índice de Estado Trófico e Índice de Parâmetros Mínimos para a Proteção da Vida Aquática, relacionando-os com a resolução Conselho Nacional do Meio Ambiente - CONAMA/357. Os resultados revelaram alterações significativas na qualidade da água da BHRB, o aumento de nutrientes e das concentrações de clorofila-a conduziram ao um estado geral de eutrofização. Os valores de surfactantes foram altos colocando em risco a biota aquática e as taxas de oxigênio dissolvido estiveram abaixo do permitido pela resolução na maioria dos pontos amostrados. A situação atual da qualidade da água para proteção da vida aquática é péssima em 61,92% dos pontos amostrados.

Palavras-chave: qualidade da água, contaminação, efluentes domésticos.

1. Introduction

Aquatic ecosystems are subjected to several stressors that change their physical, chemical, and biological functions. Those stressors originate from several punctual and diffuse sources and vary in space and time (Adams, 2001). Anthropic pressure is the classic driver of environmental change. It results from disorganized urban occupation around lakes, rivers, and estuaries, which makes them increasingly vulnerable (Williamson et al., 2008; Benvenuti et al., 2015). This urban population leads to the pollution of the river basin, which restricts the use of its waters for drinking, industry, agriculture, and leisure, and may threaten the integrity of its aquatic ecosystems (Carey et al., 2013; Massoud, 2012).

In addition, the indiscriminate use of water together with hydrological disturbance, climate change, excessive exploitation, and introduction of invasive species harm aquatic communities. Therefore, they jeopardize the biodiversity and the functioning of these ecosystems, which make the aquatic life susceptible to irreversible losses (Janse et al., 2015; Zimmermann et al., 2008; Zhang, 2007). Hence, it is crucial to protect those regions to maintain their ecological services and functions (Tundisi et al., 2014).

Water quality indices use preliminary data for the identification of potential changes that affect the sustainable use of river basins. Those indices can reflect the results of actions implemented in the river basin and point to ways for the recovery and conservation of its resources (Lobato et al., 2015; Akkoyunlu and Akiner, 2012).

Among their advantages, water quality indices facilitate the communication between scientists, politicians, and the general public. Indices are considered more reliable than isolate variables, as they can integrate several parameters in a single number (Dobbie and Dail, 2013; Hurley et al., 2012; Abaurrea et al., 2011; Lermontov et al., 2009; Štambuk-Giljanović, 1999).

The aquatic life protection index (ALPI) is one of the most complete indices to evaluate the quality of aquatic ecosystems (CETESB, 2013; Zagatto and Bertoletti, 2008). It reports water quality scenarios based on the trophic status of the environment, determine the degree of toxicity for the aquatic biota, and indicates deficiency in essential parameters for the protection of the aquatic life. Hence, the joint use of those methods helps understand degradation process of aquatic ecosystems and leads to more accurate conclusions (Rörig et al., 2007).

The aquatic life protection index is suitable for assessing Bacanga River Basin, as it is a classic example of environmental degradation through untreated discharge of sewage in its waters, among other impacts resulting from urbanization and disorganized occupation (Nascimento, 2010; Martins, 2008; Melo, 1998; Silva et al., 2014). The objective of the present study was to determine water quality in Bacanga River Basin based on the aquatic life protection index (ALPI).

2. Material and Methods

2.1. Study area

The Bacanga River Basin occupies the northwestern part of the municipality of São Luís, state of Maranhão, northeastern Brazil, between the coordinates 2° 32’ 26” and 2° 38’ 07” S and 44° 16’ 00” and 44° 19’ 16” W, with an area of 11,030 ha. The Bacanga River flows over 22 km from its source to São Marcos Bay (Figure 1). The river basin is blocked by a barrage with an irregular opening and closing regime, which impedes the water level control up to the quote of 4 m and decreases ebb and flow within the estuary.

The rivers Gapara and Bicas are the main affluents of the Bacanga River; together they compose the Environmental Protection Area of Bacanga State Park, in compliance with the State Decree # 7545 from March 2nd, 1980.

To determine the sampling sites of the present study, it was used the most recent subdivision made by Nascimento (2010), who considers five subwatersheds comprising the main water flows and neighborhoods. Hence, we carried out sampling in six sites along Bacanga River Basin (Table 1).

2.2. Methods

From 2012 to 2013, samplings were carried every two months, in a total of six events. In those sampling events, tide (ebb), moon phase (quadrature), and season (dry and rainy seasons) were considered. Three sampling events took place in the rainy season (April/12, June/12, February/13) and three in the dry season (August/12, October/12, and December /12).

The Institute of the City, Research, and Urban and Rural Planning of São Luís (Instituto da Cidade, Pesquisa e Planejamento Urbano e Rural de São Luís - INCID) provided us with data on sanitary conditions. The Environmental Sanitation Company of Maranhão (Companhia de Saneamento Ambiental do Maranhão - CAEMA) informed us the official location for the discharge of untreated sewage. The Laboratory of Meteorology of the State University of Maranhão (LabMet/UEMA) provided us with rainfall data. Physicochemical parameters are described on Table 2; most parameters were collected and measured *in situ* with a multiparameter probe model Hanna.

Those analyses followed the patterns established by Standard Methods for Water and Wastewater (APHA, 2012) and the Federal Law for the Classification of Water Bodies (National Environment Council, CONAMA 357/05) that characterizes Bacanga River Basin as a lotic environment.

The aquatic life protection index (ALPI) was calculated the by combining the index of minimum parameters for the protection of aquatic communities (IMPAC; Zagatto et al., 1999) and the trophic state index (TSI; Carlson, 1977) modified by Toledo Junior et al. (1983) for tropical environments. The formulas used for calculating the TSI followed Lamparelli (2004) for lotic environments with different trophic levels. The IMPAC was composed of two groups of parameters: toxic substances (copper, zinc, lead, chrome, mercury, nickel, cadmium, surfactants, and phenols) and essential parameters (dissolved oxygen, pH, and toxicity analyses) with weightings following CETESB (1999).

Toxicity tests followed the regulation ABNT/NBR 15088 (ABNT, 2007) adapted for the euryhaline species *Poecilia sphenops* (Feltkamp and Kristensen, 1970), considering salinity variation between sampling sites in Bacanga Lagoon. The water classification followed the values obtained for the aquatic life protection index (Table 3).

For the statistical analysis, two tests were used. In the first test, we used Euclidian distances for the ordination of sampling sites through non-metric multidimensional scaling (NMDS), with data of essential parameters (oxygen and

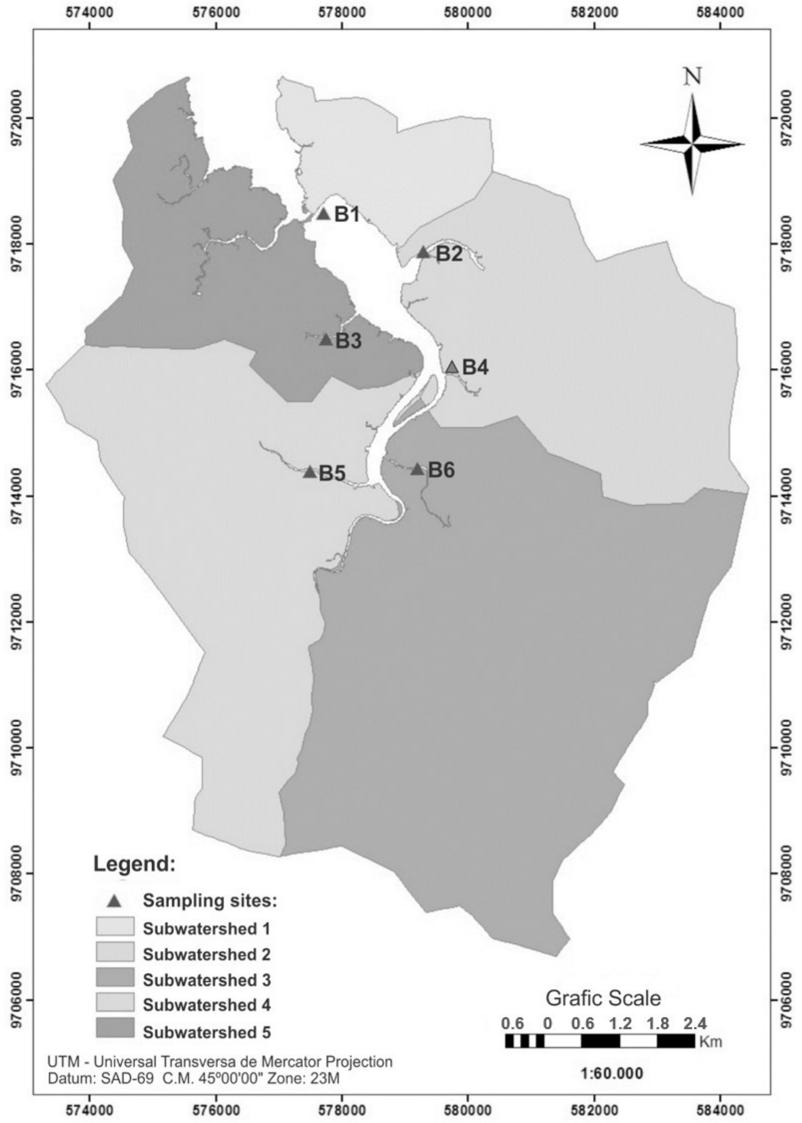

Figure 1. Sampling sites in the Bacanga River Basin.

pH), toxic substances (copper, surfactants, and phenol), and eutrophication indicators (chlorophyll-a, total phosphorous, BOD, and nitrogen compounds) submitted to a square root transformation in the software Primer - E 6.1.6. The second test comprised a principal component analysis (PCA), in which the same variables used in the previous test with standardized values analyzed in the software STATISTIC version 10 to estimate the correlation with TSI and IMPAC were considered.

3. Results

3.1. Urban sanitation condition

The main water supply of the area under the influence of Bacanga River Basin comes from the general distribution network with 46,624 points. There are 3,196 pits reported that are used for the discharge of untreated domestic sewage. Another way of sewage discharge is directly in the river, lake or sea; there are 850 points of clandestine sewage discharge, out of which 282 come from the northwestern part of the Itaqui-Bacanga area. According to the Environmental Sanitation Company of Maranhão (CAEMA), there are currently 127 official sewage discharge points throughout the city of São Luís, out of which 56 are located in Bacanga River Basin. According to those data, 90.04% of the population has access to sanitation, which has an average domestic flow of 193.69 L/s and infiltration of 42.99 L/s.

3.2. Rainfall

Rainfall from April 2012 to February 2013 summed up only 486.20 mm, out of which 194 mm were concentrated in April. There were 294 mm of rainfall on the 30 days that preceded the sampling month. February 2013 also stood out, with 3.6 mm measured on the sampling day (Figure 2).

Table 1. Sampling sites used for the calculation of the aquatic life protection index in Bacanga River Basin, northeastern Brazil.

POINTS	COORDINATES	DISTRICT
B1 DAM	**577573.98mE** **9718391.85 mS**	The Dam is the most urbanized region in the river basin, limited by a barrage that connects the metropolitan area of São Luís to its industrial complex.
B2 BICAS RIVER	**579378.10 mE** **9717993.00 mS**	The main geological tributary of Bacanga River is characterized by intense degradation and organic matter input resulting from the discharge of a large part of the city's sewage.
B3 JAMBEIRO STREAM	**577673.42 mE** **9716536.51 mS**	Jambeiro Stream undergoes a great urban influence due to the growth of the Itaqui-Bacanga region, and comprises the most populous neighborhoods of this area, including the University City of UFMA.
B4 COELHO STREAM	**579729.54 mE** **9715910.91 mS**	Coelho Stream has as the main component of urbanization the sewage discharge from four neighborhoods. It has a mixed plant cover comprising mangrove remnants dominated by a low *capoeira* (second-growth low vegetation).
B5 MAMÃO STREAM	**579359.79 mE** **9714286.72 mS**	Mamão Stream comprises parts of Bacanga State Park and Batatã Reservoir, which contributes to the water supply of São Luís Island. It has two residential neighborhoods.
B6 GAPARA RIVER	**577244.75 mE** **9714428.92 mS**	Gapara River has deforested areas due to rice crops on its mouth. There are few households on its margins, with a single neighborhood. There are also heterogeneous mangroves associated with human intervention.

Table 2. Physiochemical parameters used for calculating the aquatic life protection index in Bacanga River Basin.

VARIABLE	SYMBOL	UNITS	METHODS AND EQUIPMENTS
DEPTH	Depth	m	Graduated cable
TRANSPARENCY	Secchi	m	Secchi disk
TOTAL DISSOLVED SOLIDS	TDS	$mg.L^{-1}$	Multiparameter/Hanna
TEMPERATURE	Water Temp.	°C	Multiraparameter/Hanna
SALINITY	Sal.	---	Refractometer/ATJU
TURBIDITY	Turb.	NTU	Turbidimeter/Hanna
DISSOLVED OXYGEN	DO	$mg.L^{-1}$	Sodium azide used in the Winckler Method
BIOCHEMICAL OXYGEN DEMAND (5DAYS)	BOD_5	$mg.L^{-1}$	Sodium azide used in the Winckler Method Incubation: 5 days at 20 °C
pH	pH	---	pH-meter/ Hanna
PHENOL	Phen.	$\mu g.\ L^{-1}$	USEPA SW 846 - 8270D e 3510C, SMWW 6410B
TOTAL PHOSPHORUS	Total P	$mg.L^{-1}$	Ascorbic Acid Method/SMEWW 4500
SURFACTANTS	LAS***	$mg.L^{-1}$	POP PA023/ SMWW 5540C
AMMONIUM NITROGEN	$N\text{-}NH_4^+$	$mg.L^{-1}$	SMWW 4500 NH_3/NH_4^+
NITRATE NITROGEN	$N\text{-}NO_3^-$	$mg.L^{-1}$	Cadmium reduction Method / SMWW 4500 NO3
NITRITE NITROGEN	$N\text{-}NO_2^-$	$mg.L^{-1}$	Colorimetric Method
CADMIUM	Cd	$\mu g.\ L^{-1}$	*SMWW 3125 B
LEAD	Pb	$\mu g.\ L^{-1}$	**USEPA 6020
COPPER	Cu	$\mu g.\ L^{-1}$	
CHROME	Cr	$\mu g.\ L^{-1}$	
MANGANESE	Mn	$\mu g.\ L^{-1}$	
NICKEL	Ni	$\mu g.\ L^{-1}$	
ZINC	Zn	$\mu g.\ L^{-1}$	
CHLOROPHYLL-A	Chl-a	$\mu g.\ L^{-1}$	Spectrophotometric Parsons and Strickland (1963)

*SMWW – Standard Methods for the Examination of Water and Wastewater. **USEPA – United States Environmental Protection Agency. ***LAS - linear alkylbenzene sulphonate

October 2012 marked the dry season with no rain. In 2012, the rainfall was 995 mm a^{-1}, which, in comparison with the last ten years, was below the average (1,790 mm a^{-1}, from 2002 to 2012).

3.3. Physicochemical characterization of the water

Bacanga River Basin showed an average depth of 1.75 ± 1.25 m, a minimum value of 0.67 m (B5-February 2013) and a maximum value of 6 m (B1-April 2012). Water transparency varied from 0.26 m (B6-April 2012) to 1.50 m (B1-August 2012), with an average of 0.73 ± 0.26 m (Figure 3).

Table 3. Water quality according to the aquatic life protection index (ALPI) by Zagatto et al. (1999) modified by CETESB (2010).

Quality	Weighting
Excellent	ALPI ≤ 2.5
Good	2.6 ≤ ALPI ≤ 3.3
Regular	3.4 ≤ ALPI ≤ 4.5
Bad	4.6 ≤ ALPI ≤ 6.78
Very Bad	ALPI >6.8

The lowest water turbidity was 3.80 NTU (B1-February 2013) and the highest, 26.06 NTU (B6 –April 2012), with an average of 10.9 ± 4.79 NTU. B6 was the most turbid sampling site, in at least 33.33% of the samples. The concentration of total dissolved solids complemented the characterization of B6, and varied from 5.59 mg L^{-1} (June 2012) to 26.82 mg L^{-1} (February 2013), with an average of 19.00 ± 6.26 mg L^{-1} (Figure 3).

Salinity showed values between 2.74 g/kg (B6-April 2012) and 32.84 g/kg (B3-December 2012), with an average of 20.43 ± 9.04 g/kg, which characterized the waters as brackish. In the drainage basin, there were two horizontal salinity gradients. The first comprising B1, B2, B3, and B4 with an average of 23.44 ± 7.70 g/kg, which was an area influenced by the barrage, and the second, B5 and B6 with an average of 14.41 ± 8.77 g/kg, due to the greater fluvial input (Figure 4). Water temperature values were stable throughout the year; they varied from 27.80 °C (B3-October 2012) to 32.20 °C (B6-February 2013; Figure 4).

The minimum pH value was 6.60 (B6) and the maximum 9.93 (B1), both in April 2012, with an average

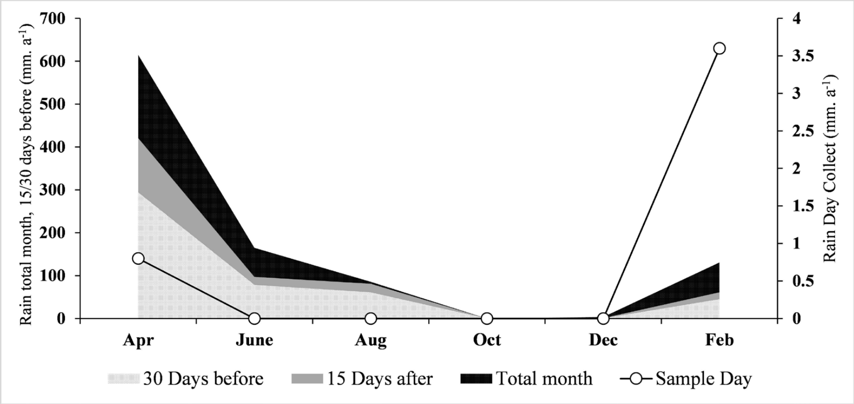

Figure 2. Total rainfall recorded in São Luís, state of Maranhão, northeastern Brazil, from April 2012 to February 2013.

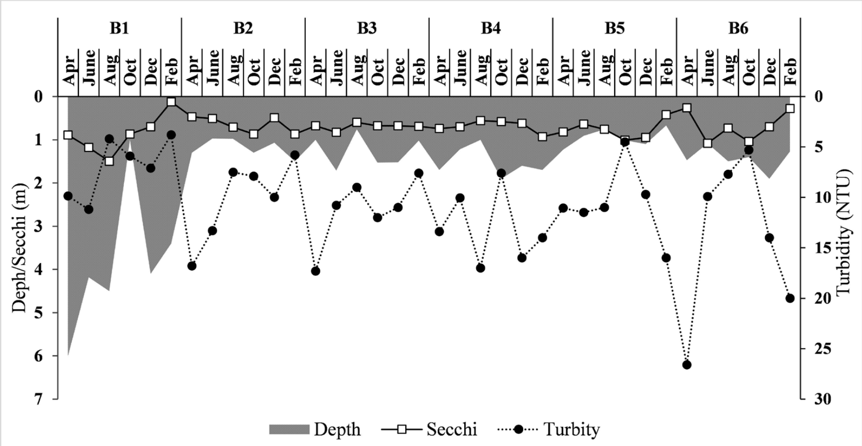

Figure 3. Distribution of depth, water transparency, and turbidity in Bacanga River Basin, São Luís, state of Maranhão, northeastern Brazil.

of 8.35 ± 0.56, which classified the environment as alkaline (Figure 5). Oxygen dissolved rates recorded a minimum value of 1.25 mg L^{-1} (B4-October 2012) and a maximum value of 15.81 mg L^{-1} in (B6-February 2013) with saturation rates of 15% and 222%, respectively, and an average of 6.06 ± 3.21 mg L^{-1}. According to the resolution CONAMA 357/05 (Brasil, 2005), the sampling sites B3 and B4 were below the threshold established in 22.22% of the samples. The sampling site B5, though, had the highest oxygenation in its waters throughout the year (83.33%), except in June 2012 (Figure 6).

BOD showed high organic matter input, with an average of 12.30 ± 7.85 mg L^{-1}, minimum of 1.15 mg L^{-1} (B2), and maximum of 32.50 mg L^{-1} (B1), both in June

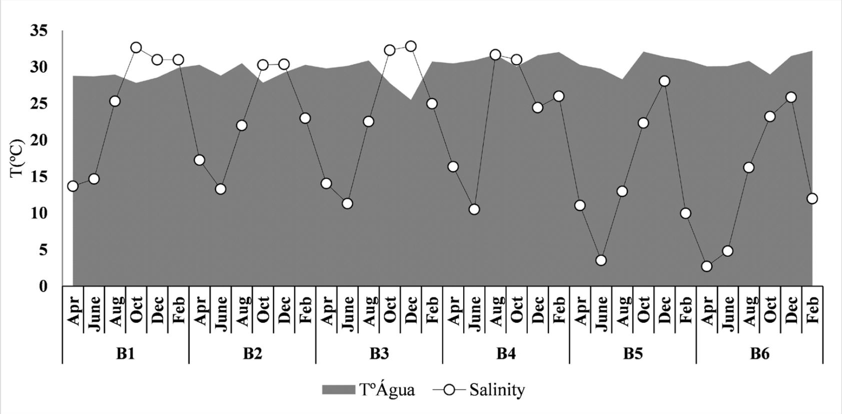

Figure 4. Distribution of temperature and salinity in Bacanga River Basin, São Luís, state of Maranhão.

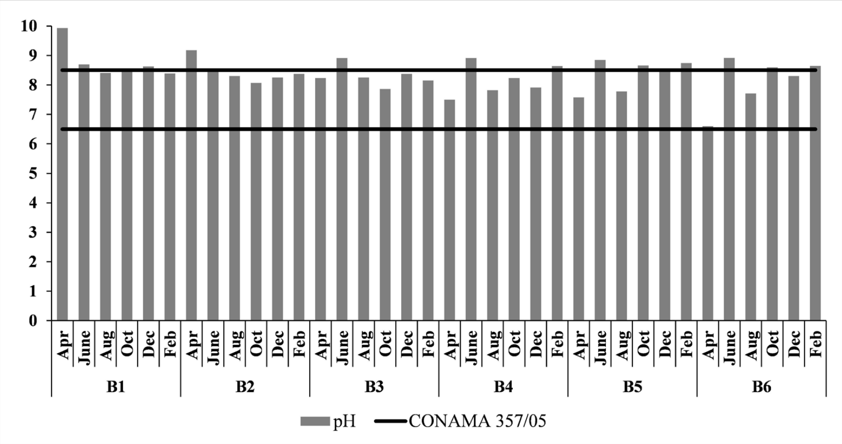

Figure 5. Distribution of the hydrogen potential in Bacanga River Basin, São Luís, state of Maranhão.

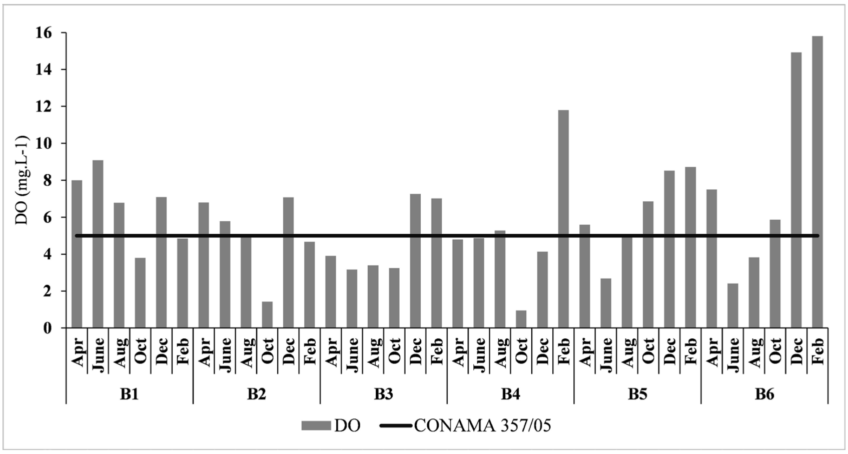

Figure 6. Distribution of dissolved oxygen (DO) in Bacanga River Basin, São Luís, state of Maranhão.

2012. The ammonia content varied from 0.001 mg L^{-1} (B1 and B3-August 2012) to 8.50 mg L^{-1} (B2 –February 13), with an average of 1.53 ± 1.81 mg L^{-1}. The nitrite content showed a minimum value of 0.00001 mg L^{-1} (B1-August 2012), a maximum value of 0.090 mg.L^{-1} (B3-February 2013), and an average of 0.02 ± 0.016 mg L^{-1}. The nitrate content were between 0.03 mg L^{-1} (B4, B6-April 2012 and B1-June 2012) and 4.90 mg L^{-1} (in all sampling sites in June 2012; Table 4).

The minimum value of total phosphorus was 0.010 mg L^{-1} (B1-October 2012), the maximum was 0.91 mg L^{-1} (B4-August 2012), and the average 1.18 ± 1.17 mg L^{-1} (Figure 7). In the group of toxic substances, Cd, Pb, and Hg were present in 100% of the samples below the limit of quantification, followed by Cr in 92.85%, Cu in 83.33%, Ni in 71.42%, and Zn in 71.42% of the samples.

In February 2013, Cu content showed high values in the entire river basin, varying from 0.1233 mg.L^{-1} (B6) to

Table 4. Average values of chemical parameters measured in Bacanga River Basin, São Luís, state of Maranhão, northeastern Brazil.

	BOD	$N\text{-}NO_3^-$	$N\text{-}NO_2^-$	$N\text{-}NH_4^+$	Total P	LAS	Phenol	TSI	
B1	32.5	4.9	0.02	1.41	0.21	2.4	0.78	75.67	Max
	2.18	0.03	0.001	0.001	0.01	0.41	0.10	56.04	Min
	15.25 ± 12.61	1.02 ± 1.90	0.01 ± 0.01	0.83 ± 0.60	0.11 ± 0.07	0.11 ± 0.07	0.27 ± 0.28	68.18 ± 6.69	Mean±SD
B2	25.26	4.9	0.02	8.5	0.37	2.2	0.28	76.84	Max
	1.15	0.30	0.01	0.80	0.14	0.10	0.10	62.30	Min
	10.96 ± 7.97	1.07 ± 1.88	0.02 ± 0.004	3.52 ± 2.95	0.24 ± 0.09	1.04 ± 0.67	0.13 ± 0.07	69.14 ± 5.00	Mean±SD
B3	14.23	4.9	0.09	1.5	0.2	5.4	0.73	72.02	Max
	7.88	0.30	0.01	0.001	0.008	0.12	0.1	57.88	Min
	11.28 ± 2.72	1.07 ± 1.88	0.04 ± 0.03	0.80 ± 0.68	0.09 ± 0.07	1.81 ± 1.89	0.35 ± 0.25	66.23 ± 4.98	Mean±SD
B4	29.02	4.9	0.03	5.5	0.91	3.4	0.62	74.96	Max
	6.04	0.30	0.01	1.5	0.07	0.16	0.1	64.35	Min
	13.07 ± 8.41	1.07 ± 1.88	0.03 ± 0.01	2.00 ± 1.61	0.28 ± 0.30	1.44 ± 1.19	0.22 ± 0.21	69.57 ± 4.04	Mean±SD
B5	19.10	4.90	0.02	0.6	0.41	2	0.53	77.83	Max
	3.35	0.30	0.01	0.002	0.06	0.10	0.10	60.68	Min
	8.99 ± 6.42	1.60 ± 2.03	0.01 ± 0.01	0.35 ± 0.26	0.17 ± 0.12	0.75 ± 0.12	0.29 ± 0.21	66.83 ± 5.97	Mean±SD
B6	24.02	4.9	0.05	1.47	0.64	3.1	0.52	80.45	Max
	5.55	0.30	0.01	0.20	0.08	0.10	0.10	62.35	Min
	12.74 ± 7.59	1.53 ± 1.99	0.03 ± 0.02	0.80 ± 0.45	0.21 ± 0.21	1.46 ± 1.03	0.29 ± 0.21	67.63 ± 7.10	Mean±SD

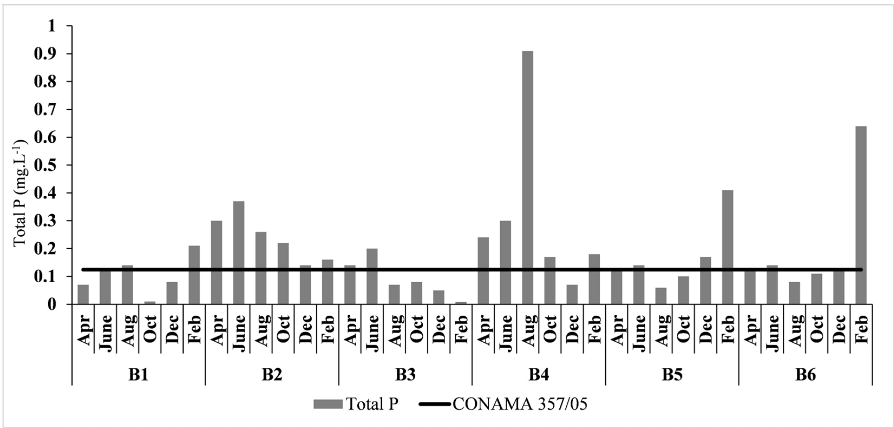

Figure 7. Distribution of total phosphorus in Bacanga River Basin, São Luís, state of Maranhão.

0.1683 mg L^{-1} (B1), with an average of 0.1415 ± 0.0167 mg L^{-1}. It directly affected the toxicity degree of this environment.

Surfactant values varied from 0.10 mg L^{-1} (B2-October 2012) to 5.40 mg L^{-1} (B3 –June 2012), with an average of 1.30 ± 1.13 mg L^{-1} (Figure 8). The concentrations of phenol were 50% below the limit of quantification established by CONAMA, and showed a minimum value of 0.00001 mg L^{-1} (B5-October 2012), a maximum value of 0.00078 mg.L^{-1} (B1-August 2012), and an average of 0.00025 ± 0.0002 mg L^{-1} (Table 4).

The minimal content of chlorophyll-a was 2.84 µg L^{-1} (B3-October 2012), the maximum content was 148.84 µg L^{-1} (B6-February 2013), with an average of 33.76 ± 36.84 µg L^{-1} (Figure 9). Water samples collected from Bacanga River Basin showed no acute toxic effect on juvenile *P. sphenops*. The fish were exposed for 96 h with no water renewal during different sampling months. Therefore, the waters of Bacanga River did not show acute toxicity for fish in the IMPAC.

3.4. Aquatic Live Protection Index (ALPI)

In Bacanga River Basin, the ALPI showed a general weighting of 7.8 that qualifies the environment as having very bad quality; at least 61.92% of the samples were classified in this category. Among the other samples, 21.42% classified the region as regular, 14.28% as bad, and only, 2.38% as good. Hence, according to the ALPI, the sampling site B4 showed the worse water quality, with the highest weighting (9.5), which classified the site as very bad. Although the sampling site B5 showed also a very bad water quality, it obtained the lowest weighting (7.0), which resulted from the lowest values of TSI and IMPAC (Figure 10).

In the dry season, Bacanga River Basin was classified as bad. It obtained the lowest weighting (5.4) in October. In the rainy season, it showed even worse conditions, with weightings of 10.3 in June 2012 and 8.6 in February 2013, which classify all sampling sites as very bad.

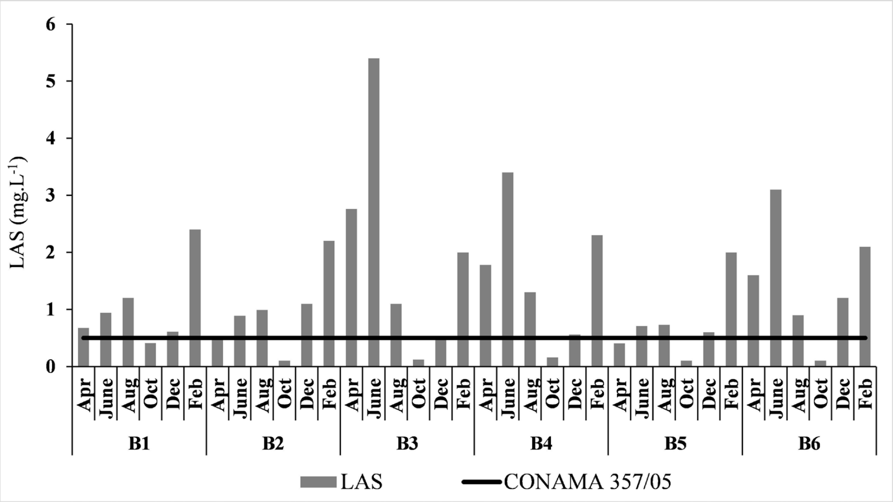

Figure 8. Distribution of surfactants in Bacanga River Basin, São Luís, state of Maranhão. LAS: linear alkylbenzene sulphonate.

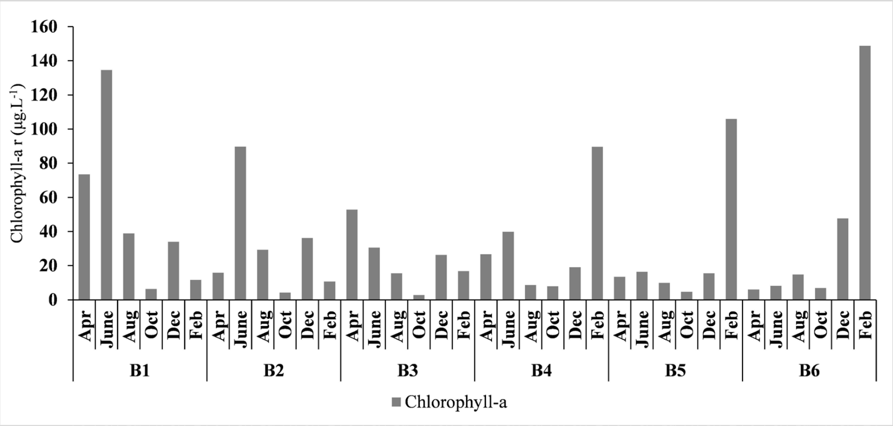

Figure 9. Distribution of chlorophyll-a in Bacanga River Basin, São Luís, state of Maranhão.

The IMPAC pointed out a process of increasing deterioration of the water in Bacanga River Basin, and classified its quality as bad, with a weighting four. The sampling sites B1, B3, B4, and B6 showed the highest weightings in 41.66% of the samples analyzed. The sampling site B4 showed a very bad situation in April 2012 and June 2012, and a predominance of the classification bad in the other sampling events.

TSI values classified the environment as hypereuthrophic with an annual average of 68.04 μg L^{-1}, and a maximal weighting equals to five. This hypereutrophic state occurred in April 2012, June 2012, and February 2013, which are months with high rainfall rate. In the dry season, the TSI varied from supereutrophic to eutrophic. The sampling sites B1, B2, and B4 recorded a hypereutrophic state in at least four sampling events.

3.5. Statistical analysis

The Non-metric Multidimensional Scaling (NMDS) formed well-defined groups in terms of trophic degree, toxicity, and organic matter discharge in Bacanga River Basin. The first group of sampling points (A) projected on the lower left-hand side of the diagram corresponds to the rainy season, when we measured the highest rates of chlorophyll-a, and classified it as hypereuthrophic based on the TSI (Figure 11).

The points on the upper right-hand side of the diagram correspond to the dry season and are subdivided in five groups. The groups B, C, and E represent the highest concentration of toxic substances in the environment, with high values of phenol and surfactants. The group B stands out in the dry season with the highest rates of nitrate, the group D with high ammonia rates, and the group F with the lowest trophic degree and toxicity (Figure 11).

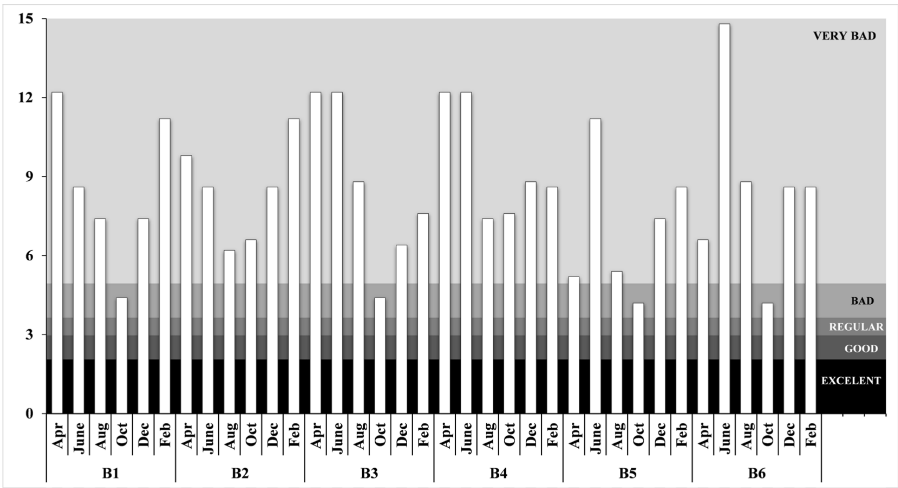

Figure 10. Distribution of the ALPI in Bacanga River Basin, São Luís, state of Maranhão.

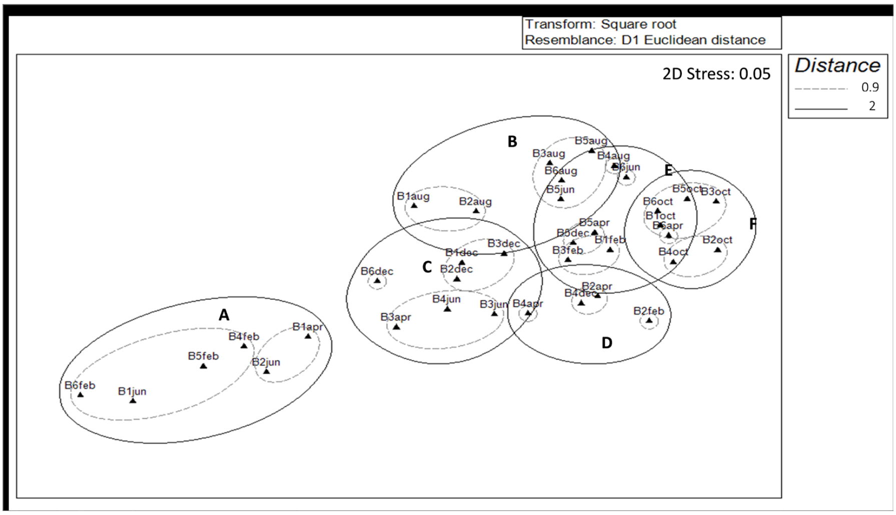

Figure 11. NMDS clustering analysis made for Bacanga River Basin, São Luís, state of Maranhão. Groups of Euclidean Distance - NMDS: A, B, C, D, E and F.

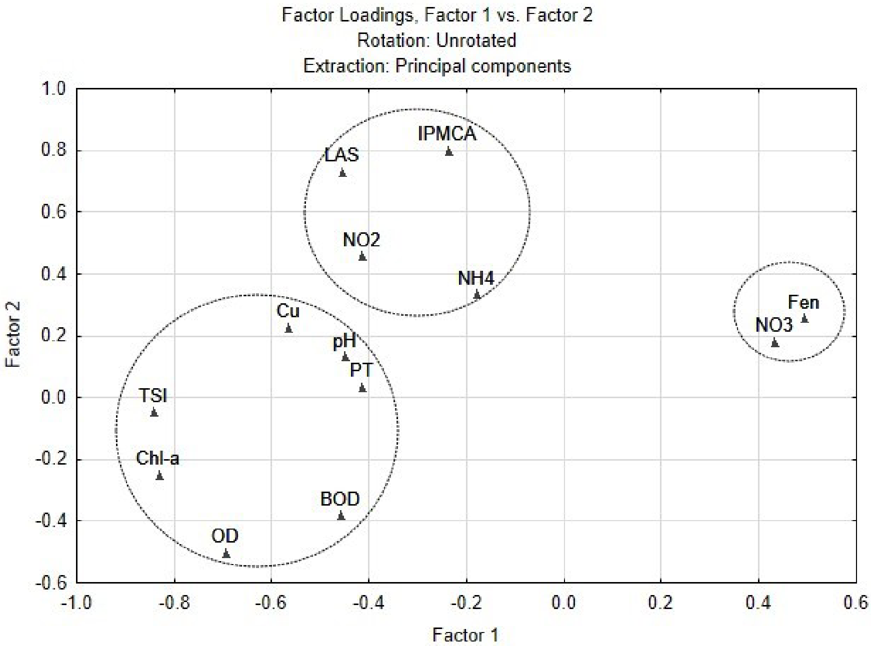

Figure 12. Bidimensional projection of the PCA in Bacanga River Basin, São Luís, state of Maranhão. Where: OD – dissolved oxygen; NO3 – nitrate nitrogen; NO2 – nitrite nitrogen; NH4 – amnion nitrogen; Cu – Copper; PT – total phosphorus; pH, LAS – Surfactants; Chl-a – chlorophyll-a; Fen. – Phenol; BOD – Biochemical Oxygen Demand (5days); TSI – Trophic State Index; and IPMCA – Index of Minimum Parameters for the Protection of Aquatic Communities (IMPAC).

The Principal Component Analysis (PCA) explained 58.81% of the variance on the three axes (Axis 1 = 28.35%, Axis 2 = 16.36%, and Axis 3 = 14.10%). The concentration of chlorophyll-a (-0.83), TSI (-0.84), and dissolved oxygen (-0.69) are negatively related on axis 1, and there was no positive correlation on this axis. The variance on axis 2 showed surfactants (0.73) and IMPAC (0.80) with a strong positive correlation, and there was no negative correlation on this axis. On axis 3, nitrate (0.70) and phenol (0.69) showed a positive correlation and ammonia (-0.58) showed a negative relationship, which did affect the determination of water quality indices for the river basin (Figure 12).

4. Discussion

Water quality indices consider local properties and the pollution status of ecosystems and can be extrapolated to the whole river basin with its urban and industrial diversity. Their main advantage is to synthesize a complex reality in a single number and to define clear goals (Akkoyunlu and Akiner, 2012; Lermontov et al., 2009; Silva and Jardim, 2006). The ALPI is a classic example of water quality indices: suitable for the protection of the aquatic life that incorporates the most representative parameters, especially toxicity and eutrophication (CETESB, 2013). In the present study, the ALPI classified Bacanga River Basin as having very bad water quality for the maintenance of aquatic organisms.

This scenario is mainly constructed by the large amount of domestic sewage produced by urban basins (Gillis, 2012; Janse et al., 2015; Konzen et al., 2015; Benvenuti et al., 2015), intensified by rainfall that potentializes the concentration of nitrogen and phosphate compounds leading to a general eutrophication state (Cunha et al., 2010; Paula et al., 2010; Butiuc-Keul et al., 2012).

There has been increasing eutrophication in Bacanga River Basin, evidenced by frequent hypereutrophication, mainly in the rainy season. The only exception was the sampling site B3, which was supereutrophic. This scenario results from the large amount of phosphorus and high concentration of chlorophyll-a (Akkoyunlu and Akiner, 2012).

However, the chlorophyll-a based TSI had high weight in the determination of the total TSI, which evidences the influence of the chlorophyll-a on the deterioration of water quality, and indicates greater assimilation of phosphate forms by phytoplankton (Lamparelli, 2004). The presence of phosphorus in watersheds during the rainy season is indicative of the entry of fertilizers, sewage and industrial due to runoff (Bortoletto et al., 2015; Carvalho et al., 2015).

This high total phosphorus load in the river basin might have favored phytoplanktonic community growth (Duarte-dos-Santos, 2013). It is worth noting that urban sources are the main agent of the eutrophication process (Souza and Gastaldini, 2014). The excessive accumulation of phytoplankton in water bodies increases oxygen rates in the environment during the day due to the increase in photosynthetic activity. We observed this phenomenon in February 2013 in B6, when the dissolved oxygen rates coincided with the highest chlorophyll-a concentration (Horne and Goldman, 1994).

However, Bacanga River Basin is a large sewage deposit in São Luís, which forms a settling pond in its mouth (Pitombeira and Morais, 1971), where there are the highest salinity, highest concentration of phenols, heavy metals, such as Cu, and the highest input of organic matter, represented by high BOD levels (Konzen et al., 2015). This high organic load can lead this ecosystem to hypoxia or anoxia states at any time of the day (Campos and Studart, 2011), and the sampling sites B3 and B4 are pointed out as critical in the region (Nascimento, 2010; Martins, 2008). IMPAC showed that those dissolved oxygen rates are insufficient to protect the aquatic life and classified the environment as very bad (Zagatto et al., 1999).

The ammoniacal nitrogen is another indicator of eutrophication of the aquatic environment (Gillis, 2012; Vasco et al., 2011; von Sperling, 2005). It was high in 66% of the sampling sites according to the threshold established by the resolution CONAMA 357/05, signaling a recent pollution by domestic sewage (Passig et al., 2015), mainly in the sampling site B2 (Nascimento, 2010; Martins, 2008; Melo, 1998; Silva et al., 2014). These concentrations can be harmful to the environment and bring serious consequences to the aquatic fauna and flora (Moruzzi et al., 2012). The risks refer not only to fish mortality, but also to the chronic effects on their reproductive capacity, growth, behavior, and biochemical and physiological changes that compromise the individual homeostasis due to the chemical stress of the environment (Silva and Jardim, 2006).

The calculation of the IMPAC showed a growing deterioration process in the water of the basin, exacerbated mainly in the sampling site B4 due to the high concentrations of surfactants and low dissolved oxygen in the water. We highlight that the surfactants (LAS) were the most representative group among the toxic substances analyzed that influenced the determination of the ALPI.

The input of those elements was constant throughout the year and intensified in the rainy season. In that season the processes of LAS degradation are slower and the urban contribution becomes more intense by the increase in leaching (Traverso-Soto et al., 2015). The presence of LAS results in severe environmental problems, both physical (dispersal of pollutants through foam, oxygen diffusion, and decrease in the photic zone) and biological (inhibition of the microorganisms responsible for the processes of natural depuration).

In addition, the LAS is deposited in the sediment causing aquatic pollution (Lewis, 1992; Delforno et al., 2014; Butiuc-Keul et al., 2012). Concerning surfactant toxic effects, the values recorded are harmful to the metabolism of fish. Surfactants damage gills, hamper respiration, and can cause suffocation. They can even cause the disappearance or inhibit growth of some species and accelerate plankton growth (Barbieri, 2005; Sueishi et al., 1988).

February 2013 stood out due to the increase in the concentration of Cu in the entire drainage basin above the threshold established by the Resolution CONAMA 357/05, with growing values towards downstream. Copper toxicity varies according to the environment exposition, chemical form, and organism and species exposed; when absorbed in excess by the aquatic biota it can cause damages that lead to death (Sanchez et al., 2005).

For Rojas et al. (2007), the concentrations of copper and zinc during the rainy season are high in BHRB considering these elements as urban discharges indicators. To Konzen et al. (2015), the presence of these metals causes deterioration of physical and chemical balance of the water, and interfere with the food chain leading to physiological and morphological changes.

Hence, the pattern of water quality for the protection of the aquatic life was very low and allowed the diagnosis of the causes of this deterioration through the results obtained. Among them, we can list the variation in dissolved oxygen leading to hypoxia status, frequent input of surfactants in the ecosystem, increase in the concentration of phosphorus and ammonium in the water. Our results pointed out sewage discharges as the main contamination source in Bacanga River Basin.

5. Conclusion

The ALPI was able to assess water quality in Bacanga River Basin, which according to the resolution CONAMA 357/05 (Brasil, 2005) was considered very bad due to the low level of dissolved oxygen, and high surfactant and ammonia rates. Out of the six sampling sites analyzed, 61.92% showed very bad water quality. The sampling site B4 (Coelho Stream) was considered the most critical and B5 (Mamão Stream) the one with the best quality, where eutrophication rates and toxic substances were lower. Based on those data, we conclude that the water quality of Bacanga River Basin is determined by the large amount of sewage discharged in its drainage system, which contaminates the aquatic life and puts it at risk.

Acknowledgements

We thank the grant given by FINEP (01.10.0714-00 CT-HIDRO) and the Master's scholarship granted to the first author by CAPES (Coordination for the Improvement of Higher Education Personnel).

References

ABAURREA, J., ASIN, J., CEBRIAN, A.C. and GARCIA-VERA, M.A., 2011. Trend analysis of water quality series based on regression models with correlated errors. *Journal of Hydrology*, vol. 400, no. 3-4, pp. 341-352. http://dx.doi.org/10.1016/j.jhydrol.2011.01.049.

ADAMS, S.M., 2001. Biomarker/bioindicator response profiles of organisms can help differentiate between sources of anthropogenic stressors in aquatic ecosystems. *Biomarkers*, vol. 6, no. 1, pp. 33-44. PMid:23886055. http://dx.doi.org/10.1080/135475001452779.

AKKOYUNLU, A. and AKINER, M.E., 2012. Pollution evaluation in streams using water quality indices: a case study from Turkey's

Sapanca Lake Basin. *Ecological Indicators*, vol. 18, pp. 501-511. http://dx.doi.org/10.1016/j.ecolind.2011.12.018.

AMERICAN PUBLIC HEALTH ASSOCIATION – APHA, 2012. *Standard methods for the examination of water and wastewater*. 22nd ed. Washington: APHA.

ASSOCIAÇÃO BRASILEIRA NORMAS TÉCNICAS – ABNT, 2007. *ABNT/NBR 15499/2007: ecotoxicologia aquática: toxidade crônica de curta duração: método de ensaio com peixes*. Rio de Janeiro. 21 p.

BARBIERI, E., 2005. Efeito do Las-C12 (Dodecil Benzeno Sulfonato de Sódio) sobre alguns parâmetros do comportamento da t*ainha (Mugil pl*a*tanus). Atlântica, Rio Grande*, vol. 27, pp. 49-57.

BENVENUTI, T., KIELING-RUBIO, M.A., KLAUCK, C.R. and RODRIGUES, M.A.S., 2015. Avaliação da qualidade da água na fonte de córregos da Bacia do Rio dos Sinos, região sul do Brasil. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 75, no. 2, suppl., pp. S98-S104. http://dx.doi.org/10.1590/1519-6984.1513.

BORTOLETTO, C.E., SILVA, H.A., BONIFÁCIO, C.M. and TAVARES, C.R.G., 2015. Acompanhamento do Pirapó bacia do Rio da qualidade da água, Paraná, Brasil. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 75, no. 4, suppl. 2, pp. S148-S157. http://dx.doi.org/10.1590/1519-6984.00313suppl.

BRASIL. Conselho Nacional do Meio Ambiente – CONAMA. 2005. *Resolução n. 357, de 17 de março de 2005. Dispõe sobre a classificação das águas doces, salobras e salinas do território nacional*. Diário Oficial da União, Brasília, 17 mar.

BUTIUC-KEUL, A., MOMEU, L., CRACIUNAS, C., DOBROTA, C., CUNA, S. and BALAS, G., 2012. Physico-chemical and biological studies on water from Aries River (Romania). *Journal of Environmental Management*, vol. 95, suppl., pp. S3-S8. PMid:21596474. http://dx.doi.org/10.1016/j.jenvman.2011.04.017.

CAMPOS, N. and STUDART, T., 2011. *Gestão de águas: princípios e práticas*. 1st ed. Porto Alegre: ABRH. 197 p.

CAREY, R.O., HOCHMUTH, G.J., MARTINEZ, C.J., BOYER, T.H., DUKES, M.D., TOOR, G.S. and CISAR, J.L., 2013. Evaluating nutrient impacts in urban watersheds: challenges and research opportunities. *Environmental Pollution*, vol. 173, pp. 138-149. PMid:23202644. http://dx.doi.org/10.1016/j.envpol.2012.10.004.

CARLSON, R.E., 1977. A trophic state index for lakes. *Limnology and Oceanography*, vol. 22, no. 2, pp. 261-269. http://dx.doi.org/10.4319/lo.1977.22.2.0361.

CARVALHO, K.Q., LIMA, S.B., PASSIG, F.H., GUSMÃO, L.K., SOUZA, D.C., KREUTZ, C., BELINI, A.D. and ARANTES, E.J., 2015. Influence of urban area on the water quality of the Campo River basin, Paraná State, Brazil. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 75, no. 4, suppl. 2, pp. S96-S106. PMid:26628235. http://dx.doi.org/10.1590/1519-6984.00413suppl.

COMPANHIA DE TECNOLOGIA DE SANEAMENTO AMBIENTAL – CETESB, 1999. *Relatório de qualidade das águas Interiores do Estado de São Paulo*. São Paulo.

COMPANHIA DE TECNOLOGIA DE SANEAMENTO AMBIENTAL – CETESB, 2010 [viewed 10 January 2010]. *Variáveis de qualidade da água* [online]. São Paulo. Available from: http://www.cetesb.sp.gov.br/Agua/rios/variaveis.asp

COMPANHIA DE TECNOLOGIA DE SANEAMENTO AMBIENTAL – CETESB, 2013. *Qualidade das águas interiores no estado de São Paulo: índices de qualidade das águas*. São Paulo. Série Relatórios.

CUNHA, D.G.F., BOTTINO, F. and CALIJURI, M.C., 2010. Land use influence on eutrophication-related water variables: case study of tropical rivers with different degrees of anthropogenic interference. *Acta Limnologica Brasiliensia*, vol. 22, no. 01, pp. 35-45. http://dx.doi.org/10.4322/actalb.02201005.

DELFORNO, T.P., MOURA, A.G.L., OKADA, D.Y. and VARESCHE, M.B.A., 2014. Effect of biomass adaptation to the degradation of anionic surfactants in laundry wastewater using EGSB reactors. *Bioresource Technology*, vol. 154, pp. 114-121. PMid:24384318. http://dx.doi.org/10.1016/j.biortech.2013.11.102.

DOBBIE, M.J. and DAIL, D., 2013. Robustness and sensitivity of weighting and aggregation in constructing composite indices. *Ecological Indicators*, vol. 29, pp. 270-277. http://dx.doi.org/10.1016/j.ecolind.2012.12.025.

DUARTE-DOS-SANTOS, A.K., 2013. *Índice de proteção da vida aquática (IVA) como ferramenta na sustentabilidade dos recursos hídricos da bacia hidrográfica do rio Bacanga, São Luís-MA*. São Luís: Universidade Federal do Maranhão, 183 p. Masters Dissertation.

FELTKAMP, C.A. and KRISTENSEN, I., 1970. *Ecology and morphological characters of different populations of Poecilia sphenops vandepolli (Cyprinidontidae)*. Hague: M. Nijhoff, pp. 102-130. Studies on the Fauna of Curaçao and other Caribbean Islands, vol. 32.1.

GILLIS, P.L., 2012. Cumulative impacts of urban runoff and municipal wastewater effluents on wild freshwater mussels (*Lasmigona costata*). *The Science of the Total Environment*, vol. 431, pp. 348-356. PMid:22705870. http://dx.doi.org/10.1016/j.scitotenv.2012.05.061.

HORNE, A.J. and GOLDMAN, C.R., 1994. *Limnology*. 2nd ed. New York: McGraw Hill.

HURLEY, T., SADIQ, R. and MAZUMDER, A., 2012. Adaptation and evaluation of the Canadian council of Ministers of the Environment Water Quality Index (CCME WQI) for use as an effective tool to characterize drinking source water quality. *Water Research*, vol. 46, no. 11, pp. 3544-3552. PMid:22521951. http://dx.doi.org/10.1016/j.watres.2012.03.061.

JANSE, J.H., KUIPER, J.J., WEIJTERS, M.J., WESTERBEEK, E.P., JEUKEN, M.H.J.L., BAKKENES, M., ALKEMADE, R., MOOIJ, W.M. and VERHOEVEN, J.T.A., 2015. GLOBIO-Aquatic, a global model of human impact on the biodiversity of inland aquatic ecosystems. *Environmental Science & Policy*, vol. 48, pp. 99-11. http://dx.doi.org/10.1016/j.envsci.2014.12.007.

KONZEN, G.B., FIGUEIREDO, J.A.S. and QUEVEDO, D.M., 2015. History of water quality parameters – a study on the Sinos River/Brazil. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 75, no. 2, suppl., pp. S1-S10. http://dx.doi.org/10.1590/1519-6984.0213.

LAMPARELLI, M.C., 2004. *Grau de trofia em corpos d'água do estado de São Paulo: avaliação dos métodos de monitoramento*. São Paulo: Instituto de Biociências, Universidade de São Paulo, 238 p. PhD Thesis.

LERMONTOV, A., YOKOYAMA, L., LERMONTOV, M. and MACHADO, M.A.S., 2009. River quality analysis using fuzzy water quality index: Ribeira do Iguape river watershed, Brazil. *Ecological Indicators*, vol. 9, no. 6, pp. 1188-1197. http://dx.doi.org/10.1016/j.ecolind.2009.02.006.

LEWIS, M.A., 1992. The effects of mixtures and other environmental modifying factors on the toxicities of surfactants to freshwater and marine life. *Water Research*, vol. 26, no. 8, pp. 1013-1023. http://dx.doi.org/10.1016/0043-1354(92)90136-R.

LOBATO, T.C., HAUSER-DAVIS, R.A., OLIVEIRA, T.F., SILVEIRA, A.M., SILVA, H.A.N., TAVARES, M.R.M. and SARAIVA, A.C.F., 2015. Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: A case study in the Amazon region. *Journal of Hydrology*, vol. 522, pp. 674-683. http://dx.doi.org/10.1016/j.jhydrol.2015.01.021.

MARTINS, A.L.P., 2008. *Avaliação da qualidade ambiental da bacia hidrográfica do Bacanga (São Luís - MA) com base em variáveis físico-químicas, biológicas e populacionais: subsídios para um manejo sustentável*. São Luís: Universidade Federal do Maranhão, 88 p. Masters Dissertation.

MASSOUD, M.A., 2012. Assessment of water quality along a recreational section of the Damour River in Lebanon using the water quality index. *Environmental Monitoring and Assessment*, vol. 184, no. 7, pp. 4151-4160. PMid:21853414. http://dx.doi.org/10.1007/s10661-011-2251-z.

MELO, O.T., 1998. *Comportamento biogeoquímico de nutrientes no estuário do Rio Bacanga - Ilha de São Luís*. Belém: Universidade Federal do Pará, 118 p. Masters Dissertation.

MORUZZI, R.B., CONCEIÇÃO, F.T., SARDINHA, D.S., HONDA, F.P. and NAVARRO, G.R.B., 2012. Avaliação de cargas difusas e simulação de autodepuração no córrego da Água Branca, Itirapina (SP). *Geociências*, vol. 31, pp. 447-458.

NASCIMENTO, J.D., 2010. *O Índice de Sustentabilidade Ambiental do Uso da Água (ISA) como ferramenta de contribuição às políticas públicas de desenvolvimento e conservação na bacia do Bacanga, São Luís/MA*. São Luís: Universidade Federal do Maranhão, 99 p. Masters Dissertation.

PARSONS, T.R. and STRICKLAND, J.D.H., 1963. Discussion of spectrophotometric determination of marine plankton pigments, with revised equations of as certaning chlorophyll *a* and carotenoids. *Journal of Marine Research*, vol. 21, pp. 155-163.

PASSIG, F.H., LIMA, S.B., CARVALHO, K.Q., HALMEMAN, M.C.R., SOUZA, P.C. and GUSMÃO, L.K., 2015. Monitoramento de bacias urbanas e rurais: a qualidade da água da bacia Mourão. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 75, no. 4, suppl. 2, pp. S158-S164. http://dx.doi.org/10.1590/1519-6984.01213suppl.

PAULA, F.C.F., LACERDA, L.D., MARINS, R.V., AGUIAR, J.E., OVALLE, Á.R.C. and FALCÃO FILHO, C.A.T., 2010. Emissões naturais e antrópicas de metais e nutrientes para a bacia inferior do rio de contas, Bahia. *Química Nova*, vol. 33, no. 1, pp. 70-75. http://dx.doi.org/10.1590/S0100-40422010000100014.

PITOMBEIRA, E.S. and MORAIS, J.O., 1971. Ciclo hidrodinâmico e sedimentológico do estuário do Rio Bacanga (São Luís, Estado do Maranhão, Brasil). *Arquivos Ciências do Mar*, vol. 17, pp. 165-174.

ROJAS, M., CAVALCANTE, P.R.S., SOUZA, R.C. and DOURADO, E.C.S., 2007. Teores de Zinco e Cobre em ostra (Crassotrea rhizophorae) e sururu (Mytella falcata) do estuario do rio Bacanga em São Luís (MA). *Boletim do Laboratório de Hidrobiologia*, vol. 20, pp. 1-8.

RÖRIG, L.R., TUNDISI, J.G., SCHETTINI, C.A.F., PEREIRA-FILHO, J., MENEZES, J.T., ALMEIDA, T.C.M., URBAN, S.R., RADETSKI, C.M., SPERB, R.C., STRAMOSK, C.A., MACEDO, R.S., CASTRO-SILVA, M.A. and PEREZ, J.A., 2007. From a water resource to a point pollution source: the daily journey of a coastal urban stream. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 67, no. 4, pp. 597-609. PMid:18278310. http://dx.doi.org/10.1590/S1519-69842007000400003.

SANCHEZ, W., PALLUEL, O., MEUNIER, L., COQUERY, M., PORCHER, J.M. and AIT-AISSA, S., 2005. Copper-induced oxidative stress in three-spined stickleback, relationship with hepatic metal levels. *Environmental Toxicology and Pharmacology*, vol. 19, no. 1, pp. 177-183. PMid:21783474. http://dx.doi.org/10.1016/j.etap.2004.07.003.

SILVA, G.S. and JARDIM, W.F., 2006. Um novo índice de qualidade das águas para proteção da vida aquática aplicado ao Rio Atibaia, Região de Campinas/Paulínia - SP. *Química Nova*, vol. 29, no. 4, pp. 689-694. http://dx.doi.org/10.1590/S0100-40422006000400012.

SILVA, G.S., SANTOS, E.A., CORRÊA, L.B., BRANDES, A.L.M., MARQUES, E.P., SOUSA, E.R. and SILVA, G.S., 2014. Avaliação integrada da qualidade de águas superficiais: grau de trofia e proteção da vida aquática nos rios Anil e Bacanga, São Luís (MA). *Engenharia Sanitaria e Ambiental*, vol. 19, no. 3, pp. 245-250. http://dx.doi.org/10.1590/S1413-41522014019000000438.

SOUZA, M.M. and GASTALDINI, M.C.C., 2014. Avaliação da qualidade da água em bacias hidrográficas com diferentes impactos antrópicos. *Engenharia Sanitária e Ambiental*, vol. 19, no. 3, pp. 263-274. http://dx.doi.org/10.1590/S1413-41522014019000001097.

ŠTAMBUK-GILJANOVIĆ, N., 1999. Water quality evaluation by Index in Dalmatia. *Water Research*, vol. 33, no. 16, pp. 3423-3440. http://dx.doi.org/10.1016/S0043-1354(99)00063-9.

SUEISHI, T., MORIOKA, T., KANEKO, H., KUSAKA, M., YAGI, S. and CHIKAMI, S., 1988. Environmental risk assessment of surfactants: Fate and environmental effects in Lake Biwa basin. *Regulatory Toxicology and Pharmacology*, vol. 8, no. 1, pp. 4-21. PMid:3368585. http://dx.doi.org/10.1016/0273-2300(88)90003-7.

TOLEDO JUNIOR, A.P., TALARICO, M., CHINEZ, S.J. and AGUDO, E.G., 1983. A aplicação de modelos simplificados para a avaliação do processo da eutrofização em lagos e reservatórios tropicais. In: *Anais do 12º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, 1983, Balneário Camboriú. Curitiba: SUREHMA, pp. 1-34.

TRAVERSO-SOTO, J.M., LARA-MARTÍN, P.A., GONZÁLEZ-MAZO, E. and LEÓN, V.M., 2015. Distribution of anionic and nonionic surfactants in a sewage-impacted Mediterranean coastal lagoon: Inputs and seasonal variations. *The Science of the Total Environment*, vol. 503–504, pp. 87-96. PMid:25046983. http://dx.doi.org/10.1016/j.scitotenv.2014.06.107.

TUNDISI, J.G., GOLDEMBERG, J., MATSUMURA-TUNDISI, T. and SARAIVA, A.C.F., 2014. How many more dams in the Amazon? *Energy Policy*, vol. 74, pp. 703-708. http://dx.doi.org/10.1016/j.enpol.2014.07.013.

VASCO, A.N.V., BRITTO, F.B., PEREIRA, A.P.S., MÉLLO JÚNIOR, A.V., GARCIA, C.A.B. and NOGUEIRA, L.C., 2011. Avaliação espacial e temporal da qualidade da água na sub-bacia do rio Poxim, Sergipe, Brasil. *Revista Ambiente & Água*, vol. 6, no. 1, pp. 118-130. http://dx.doi.org/10.4136/ambi-agua.178.

VON SPERLING, M., 2005. *Introdução à qualidade das águas e ao tratamento de esgotos*. Belo Horizonte: Departamento de Engenharia Sanitária e Ambiental, UFMG.

WILLIAMSON, C.E., DODDS, W., KRATZ, T.K. and PALMER, M.A., 2008. Lakes and streams as sentinels of environmental change in terrestrial and atmospheric processes. *Frontiers in Ecology and the Environment*, vol. 6, no. 5, pp. 247-254. http://dx.doi.org/10.1890/070140.

ZAGATTO, P.A. and BERTOLETTI, E., 2008. *Ecotoxicologia aquática: princípios e aplicações*. 2nd ed. São Carlos: RiMa.

ZAGATTO, P.A., LORENZETTI, M.L., LAMPARELLI, M.C., SALVADOR, M.E.P. and MENEGON, J.R., 1999. Aperfeiçoamento de um índice de qualidade de águas. *Acta Limnologica Brasiliensia*, vol. 11, pp. 11-129.

ZHANG, H., 2007. The orientation of water quality variation from the metropolis river-Huangpu River, Shanghai. *Environmental Monitoring and Assessment*, vol. 127, no. 1-3, pp. 429-434. PMid:16957852. http://dx.doi.org/10.1007/s10661-006-9292-8.

ZIMMERMANN, C.M., GUIMARÃES, O.M. and PERALTA-ZAMORA, P.G., 2008. Avaliação da qualidade do corpo hídrico do rio Tibagi na região de Ponta Grossa utilizando análise de componentes principais (PCA). *Química Nova*, vol. 31, no. 7, pp. 1727-1732. http://dx.doi.org/10.1590/S0100-40422008000700025.