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Multivariate Analysis of Amazonian Rivers Located in an Area of Intense Industrial Activity, Barcarena, Pará State, Brazil

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Abstract

In this study, were multivariate analysis of the waters of the Arienga and Murucupí rivers located near an area of intense industrial activity in the Barcarena City, Pará State, Brazil. Were analyzed the variables temperature, pH, total dissolved solids, electrical conductivity, DO, BOD, ammoniacal-N, nitrite-N, nitrate-N, phosphate, sulfate and total hardness in four sampling campaigns in the year 2011. This amazon rivers presented physicochemical characteristics well heterogeneous, but similar behaviors for the variables pH, temperature and DO in the extensions evaluated, that is, increase in the source-mouth direction, with variations from 4.77 to 7.33 and 5.51 to 7.3, 25 to 31°C and 27 to 32°C and from 4.4 to 7.98 mg.L^{-1} and 1.17 to 6.55 mg.L^{-1} for the Arienga and Murucupi rivers respectively. In addition to these characteristics, the Arienga River also presented an increase for ammoniacal-N, nitrite-N, nitrate-N and hardness in the dry period, with variations from 0.014 to 6.336 mg.L^{-1}, 0.005 to 0.334 mg.L^{-1}, 0.009 to 4.818 mg.L^{-1} and 1.146 to 14.389 mg.L^{-1} respectively. In general, Murucupí River presented different physicochemical characteristics that are coherent with the local scenario, where the launch domestic effluents and the environmental impacts caused by industrial waste are visible and recurrent respectively.

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Introduction

The quality of surface water depends on many factors, and may undergo hydroclimatic influences such as natural weathering and environmental changes caused by anthropic actions[1]. The various environmental factors that modify the water quality of a given region are related to the geological structure, the mineralogy of the watersheds and the way in which the use and occupation of the soil occurs in the surroundings of these areas [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12].

Household and industrial effluents generated from human activities may contain hazardous chemicals that can cause major impacts on aquatic ecosystems. These substances can last a long time in the environment and have the ability to percolate in the soil and reach the lower layers of the subterranean aquifers, for this reason, soil geochemistry has a great influence on water pollution/contamination [13].

In recent decades there has been a great increase in the levels of toxic chemicals in the environment, this event is a consequence of the lack of planning by the municipalities and industries installed in relation to the way the effluents are released in the water bodies generating immense release of compounds Harmful to animal and plant life [14,15,16].

The Barcarena City in the Pará State-Brazil has in its territory an important industrial pole that works in the processing and export of kaolin, alumina, aluminum, cables for transmission of electric energy among other activities. Approximately 40,000 hectares were used for the installation of industries and the local population that previously used natural resources for their livelihoods, such as hunting and fishing, had to adopt other productive bases for their economic survival[17]. The local economy has a traditional base in agriculture, but also advances with tourism beyond industrial activities, generating economic growth[18]. The presence of these industries causes the rivers to become targets of recorrent environmental accidents, for example, the spillage of red mud in the springs of the Murucupí river in April 2009, a product from the beneficiation of bauxite that caused great environmental damages and to the local population[19].

The launch of untreated sanitary sewage and the recorrent environmental accidents have damaged the quality of the waters of that region. In this sense, the Murucupí River was chosen, which runs through the industrial area of Vila do Conde and urban agglomerates and the Arienga River, which is located in the territorial boundary between the cities of Barcarena and Abaetetuba, Pará State-Brazil, a little further away from industrial area.

Material and Methods

Study Area

The Barcarena City belongs to the mesoregion Metropolitana de Belém, Pará State-Brazil, located under the geographical coordinates: 01º 30′ 24″ of South latitude e 48º 37′ 12″ Longitude west of Greenwich, with straight line distancing from the state capital (Belém, Pará) in approximately 30 km [20]. This City is part of the Pará river basin and has a territorial area of 1,310 km^2 in size; the estimated population for 2016 was 118,537 inhabitants[21].

The climate of the microregion is Köeppen wet type Am, with abundant rainfall and high temperature values reaching an annual average of 27º C, The annual rainfall is over 2,000 mm where two seasonal periods are well defined: The rainy season from December to May and dry from June to November [22]. Table 1 shows some regional climate characteristics in 2011, according meteorological data base and tidal forecasts [23, 24].

The geology of the Municipality is constituted by a set of aquifers belonging to the stratigraphic units Pirabas, Barreiras and Quaternary Coverage[25,26]. Topographic levels are low, especially on islands where they are in part subject to floods [27,28].

Arienga River microbasin is located in the territorial area between the cities of Barcarena, Abaetetuba and Moju in the Pará State-Brazil. This river territorially delimits Barcarena and Abaetetuba cities, has their springs located within these cities, with the mouth in the right bank of the river Pará and also are used by the local population for recreation in existing beach resorts along the river. The microbasin of the Murucupí river is located in the territorial area of the Barcarena between the mining companies Albrás and Alunorte and the districts of Vila dos Cabanos and

Table 1. Regional climate characteristics in 2011.

Local characteristics	Unit	Months of Sampling							
		February (Rainy)		May (Rainy)		August (Dry)		November (Dry)	
		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Temperature	°C	31.0	23.1	33.5	24.3	33.9	23.3	33.1	22.7
Tides	m	3.5	-0.2	3.2	-0.2	3.5	-0.1	3.2	-0.3
*Rainfall	mm	332.4		477.3		179.4		174.6	

*- Monthly precipitation; Max.: Maximum; Min.: Minimum.

Laranjal. Its source is located near the tailings basin of the company Alunorte (Mud Red) and its mouth in the Furo do Arrozal River [19].

The classification of the rivers in the Amazon fall into three categories: white, dark and clear waters. According to the classification of the waters as their colorations, the pH between 4.0 and 7.0 configures a clear water environment, while waters with pH around 4.0 are classified as black, therefore, the waters of the rivers Arienga and Murucupí present the two classifications [29,30,31].

Based on the Brazilian legislation that provides for the classification of water bodies and environmental guidelines for their classification[32], regarding the salinity of the water bodies, the Arienga and Murucupí rivers presented values consistent with the classification for freshwater.

In the Arienga river, an extension of approximately 11,368 m was evaluated, considering six (06) sampling points with minimum and maximum distance between sampling points of 1,546 m and 2,672 m respectively. In the Murucupí River, seven (07) sampling points were evaluated in an extension of approximately 6,333 m, with minimum and maximum distance between the sampling points of 737 m and 1,725 m respectively. The sampling points (Fig. 1) in the Arienga and Murucupí rivers were defined upstream and downstream of small tributary drains along the extensions evaluated from their source to their mouths, taking into account navigability, accessibility, field staff and financial cost to carry out the work.

Sampling and Analysis Methodologies

The samples and analyzes used to determine the variables obeyed the procedures and methodologies according to the recommendations described in the Standard Methods for Examination of Water and Wastewater [33].

Sampling for the determination of the physico-chemical variables at the collection points was of the simple type and using the immersion technique of the collection vessels at a maximum depth of 30 cm from the water column. The water samples were collected in duplicates in polyethylene bottles with capacity for 1L and then transported in isothermal boxes preserved with recyclable ice and taken to the Laboratory of Toxicology Of the Environment Section of the Evandro Chagas Institute in Ananindeua-PA.

The physicochemical variables determined were: temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), ammoniacal-N, nitrite-N, nitrate-N, phosphate, sulfate and total hardness ($CaCO_3$ and $MgCO_3$).

The temperature, pH, total dissolved solids, electrical conductivity and dissolved oxygen were determined at the moment of sampling with the HI 769828 equipment of the HANNA® previously calibrated with standard solutions. The determination of BOD_5 at 20 ° C was performed on the BODTRAK of the HACH®.

For analysis of ammoniacal-N, nitrite-N, nitrate-N, phosphate, sulfate and total hardness, the samples were filtered through a 0.45 μm pore Millipore

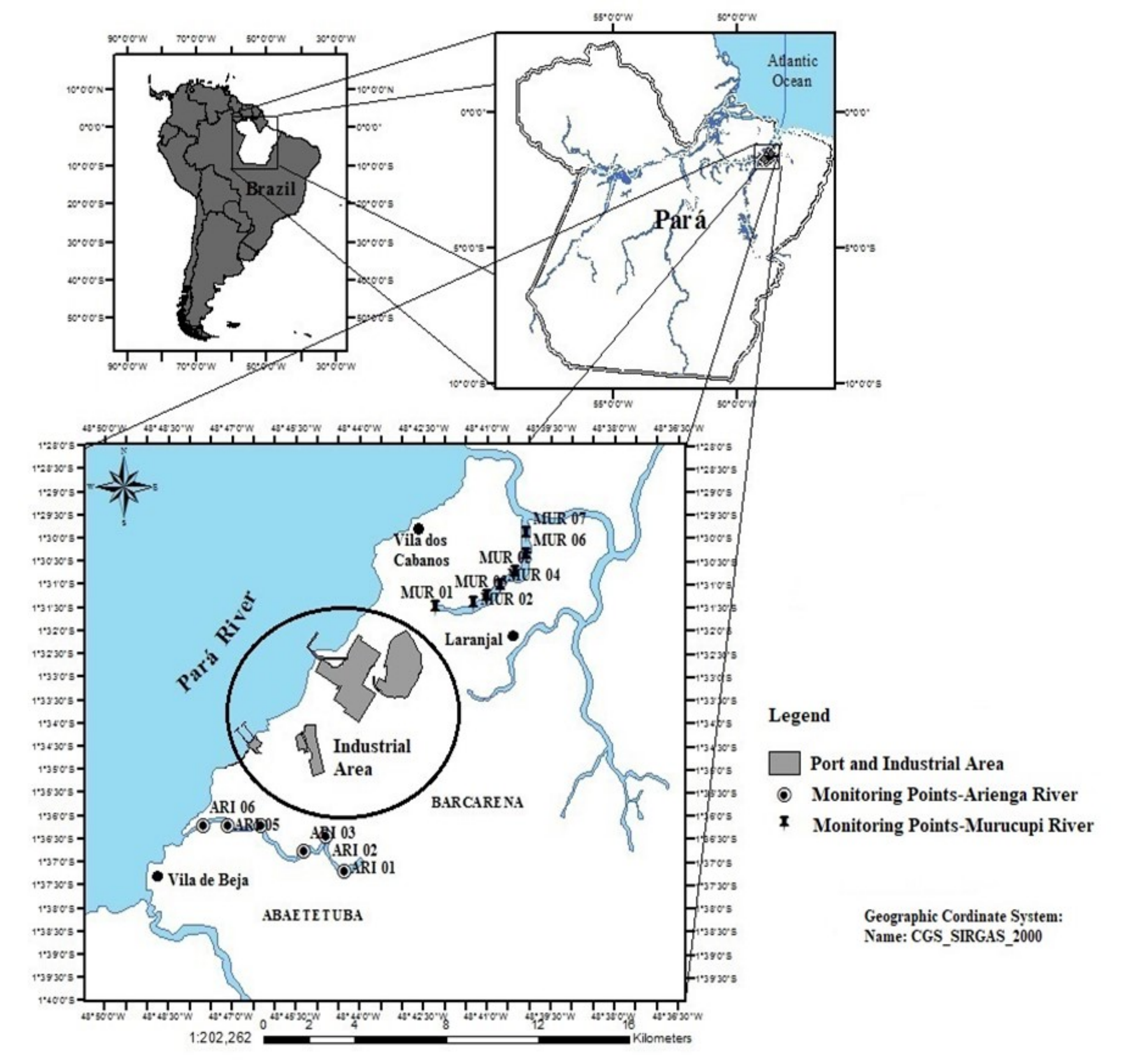

Figure 1. Study area and respective sampling points.

filter and then analyzed via ion chromatography in a system ICS 2000 DUAL [34].

Statistical Treatment

Descriptive statistics and principal component analysis (PCA) were applied on the results of the physicochemical variables determined in the two rivers. Minitab 17 software (license 317201144883580098) was used for the application of the descriptive statistics and multivariate analysis about the data. The results were compared between rainy and dry seasons.

Results

This study, the water temperature of the Arienga and Murucupi rivers ranged from 25 to 31 °C and from 27 to 32 °C, respectively, with average variations from 26 to 30 °C. The pH values in this study ranged from 4.75 to 7.33 in the Arienga river and from 5.51 to 7.3 in the Murucupi river, with means ranging from 5.55 to 6.71.

The electrical conductivity and total dissolved solids (TDS) determined in the rivers Arienga and Murucupí indicated a difference in its characteristics physicochemical, with values ranging from 4 to 49 $\mu S.cm^{-1}$ and 25 to 122 $\mu S.cm^{-1}$ e from 2 to 26 $mg.L^{-1}$ and 12 to 57 $mg.L^{-1}$ respectively, the mean electrical conductivity and TDS in the Arienga river were 21 to 25 $\mu S.cm^{-1}$ and 11 to 13 $mg.L^{-1}$ and Murucupi River from 38 to 83 $\mu S.cm^{-1}$ and 19 to 38 $mg.L^{-1}$.

The DO concentrations in the Arienga and Murucupi rivers ranged from 4.40 to 7.98 $mg.L^{-1}$ and from 1.17 to 6.55 $mg.L^{-1}$ respectively, with averages from 5.21 to 6.29 $mg.L^{-1}$ in the Arienga River and from 3.86 to 4.70 $mg.L^{-1}$ in the Murucupi River. The BOD concentrations in the Arienga and Murucupi rivers ranged from 5 to 19 $mg.L^{-1}$ and from 6 to 26 $mg.L^{-1}$ respectively, with averages ranging from 9 to 15 $mg.L^{-1}$ in the two rivers.

The ammonia nitrogen, nitrite and nitrate concentrations in the Arienga and Murucupi rivers ranged from 0.014 to 6.336 $mg.L^{-1}$, 0.003 to 0.334 $mg.L^{-1}$ and 0.009 to 4.818 $mg.L^{-1}$ and from 0.021 to 2.021 $mg.L^{-1}$, 0.001 to 0.406 $mg.L^{-1}$ and 0.025 to 4.201 $mg.L^{-1}$ respectively, with averages from 0.062 a 1.496 $mg.L^{-1}$ (ammonia nitrogen), 0.019 to 0.080 $mg.L^{-1}$ (nitrite) and 0.075 to 0.679 $mg.L^{-1}$ (nitrate) in the Arienga River and from 0.248 to 0.392 $mg.L^{-1}$ (ammonia nitrogen), 0.047 to 0.121 $mg.L^{-1}$ (nitrite) and 0.791 to 1.247 $mg.L^{-1}$ (nitrate) in the Murucupi River.

The phosphate concentrations in the Arienga and Murucupi rivers ranged from 0.014 to 0.239 $mg.L^{-1}$ and from 0.056 to 0.313 $mg.L^{-1}$ respectively, with averages from 0.064 to 0.117 $mg.L^{-1}$ in the Arienga River and from 0.109 to 0.187 $mg.L^{-1}$ in the Murucupi River. The sulfate concentrations in the Arienga and Murucupi rivers ranged from 0.011 to 4.886 $mg.L^{-1}$ and from 0.897 to 5.367 $mg.L^{-1}$ respectively, with averages from 0.812 to 1.347 $mg.L^{-1}$ in the Arienga River and from 1.743 to 2.474 $mg.L^{-1}$ in the Murucupi River. The highest concentrations of total hardness in the Arienga and Murucupí rivers occurred in the dry period, with variations from 0.232 to 14.389 $mg.L^{-1}$ and from 0.112 to 18.568 $mg.L^{-1}$ respectively, with averages from 2.823 to 5.824 $mg.L^{-1}$ in the Arienga River and from 3.101 to 8.769 $mg.L^{-1}$ in the Murucupi River.

From the analytical data obtained in this study it was possible to compare water quality of the Arienga and Murucupí rivers through groups formed by principal components in correlation matrices by degree of similarity.

The physicochemical results of the rainy season for ebbing and flooding tide conditions provided the formation of 3 well defined groups as observed in Fig. 2A, that is, in PC1 (43.5%), there was an optimal separation between groups 1 and 3 , in which most of the sampling points of the rivers Arienga and Murucupí are observed. Similar characteristics were observed in relation to group 2 formed in PC2 (20.4%) by sampling points close to the mouths of the Arienga and Murucupí rivers. In general, there is a transition in the physical-chemical characteristics of these waters between the sampling points in those of the extensions evaluated.

In Fig. 2B, referring to factorial load analyzes for two components, it was evidenced that the levels of dissolved oxygen and BOD represented the main factors for the formation of group 1 in the river Arienga, in this river a homogeneous characteristic was observed for BOD with higher values At the ends (springs and mouth) of the evaluated and heterogeneous extension to DO with increasing levels

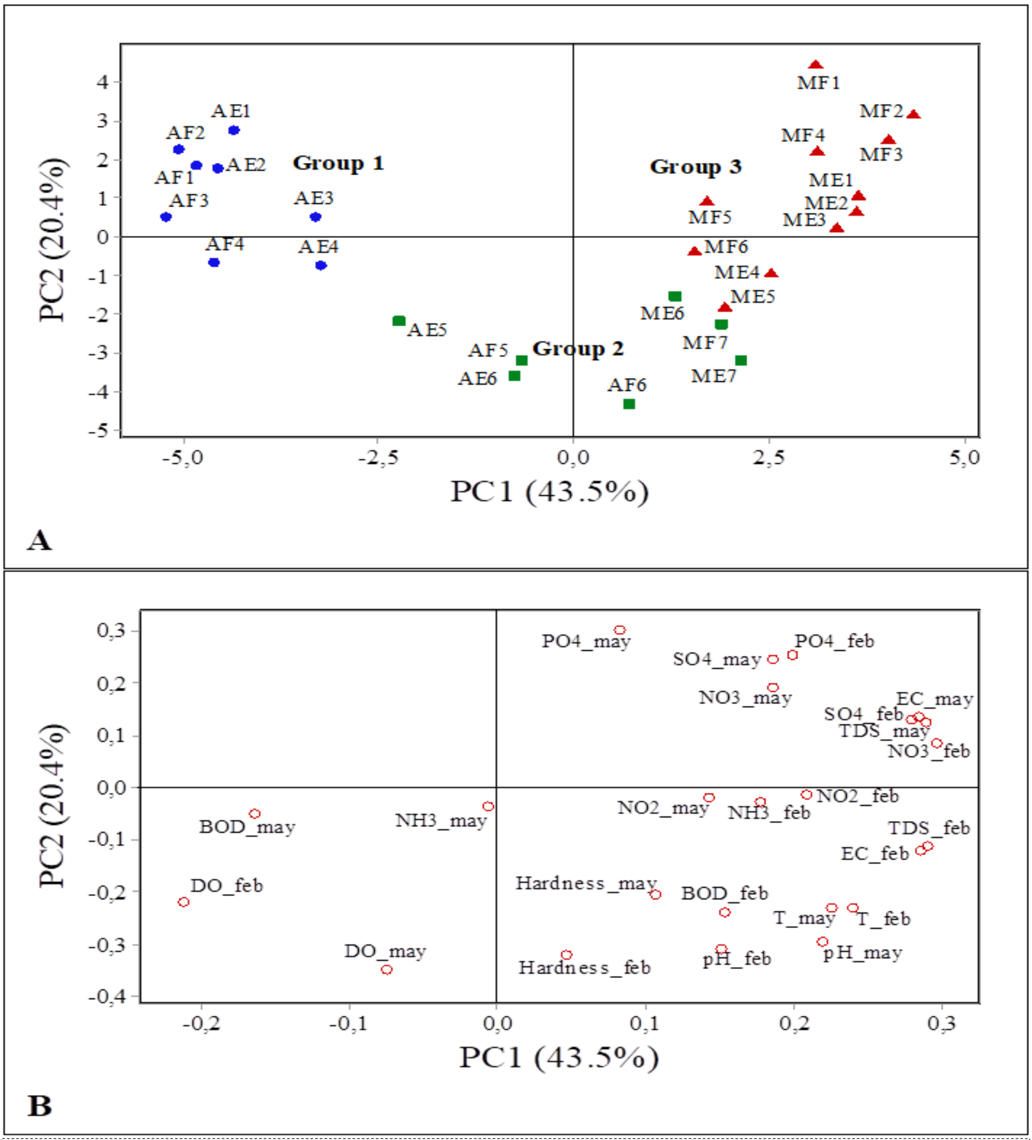

Figure 2. Analysis of main components of the score plot type (A) and loading plot (B) on the data of variables determined during the rainy season (February and May) under ebbing and flooding tide conditions in 2011. Note: AE (Arienga ebbing tide); AF (Arienga flooding Tide); ME (Murucupí ebbing tide); MF (Murucupí flooding tide).

from the sources to its mouth in the Pará river, this behavior is probably related to several factors such as the presence and decomposition of organic matter introduced in the extension evaluated by other tributary water bodies, miscegenation and contribution of leachate materials in these waters due to the higher rainfall intensity in the seasonal period in question and the larger aeration area in its mouth.

In group 2, the physicochemical variables that had the same behavior were pH, temperature, DO, BOD and Hardness, therefore, the two rivers presented the same characteristics in their mouths for these variables. The variables that contributed most to the formation of group 3 were: electrical conductivity, total dissolved solids, ammoniacal nitrogen, nitrite, nitrate, sulfate and phosphate, showing that there is interference in the water quality of the river Murucupí by pollutants characteristic of domestic sewage originating from the communities located around this water body, especially at the sampling points closest to its sources. The environmental impacts caused by the spillage of chemical wastes in these waters over the years, can also have their degree of contribution in the water quality conditions of the Murucupí River from the release gradual of residues from the bottom sediment.

Similar to the rainy season, the PC1 (43.4%) of Fig. 3A (dry season) shows the formation of three groups (1, 2 and 3). Groups 1 and 2 presented similarity of 39.79% and were formed by most of the sampling points of the Arienga river, this time, in group 2, the sampling points located at the mouth of the river Arienga (AE6, AF5 and AF6) (ME1 and MF1), evidencing well heterogeneous characteristics in the waters of the Murucupí River, probably due to the lower influence of the rainfall in this seasonal period and consequently the greater concentration and dispersion of the variables analyzed.

In the analyzes of factorial loads for two components on the data of the dry season (Fig. 3B), it was observed that there was greater influence of the variables OD, BOD and ammonia nitrogen for the formation of group 1. In group 2, there was a greater influence of the BOD variable in the sampling points of the mouth of the river Arienga (AE5, AE6, AF4, AF5 and AF5) and of the nitrate and phosphate variables at the point of the Murucupí sources (ME1 and MF1). Group 3 repeated the same behavior of rainy season, where it was evidenced changes in concentration of variables, most likely by the influence of domestic sewage, a situation observed in field work through the visualization of emissaries (pipes) of wastewater located on the banks of the Murucupí River.

Tables 2 and 3 are the descriptive statistics (mean, standard deviation, maximum values and minimum values) applied to the values of the physicochemical variables determined in the rivers Arienga and Murucupí respectively, in the rainy (February and May) and dry (August and November) in ebbing and flooding tide conditions in 2011.

Discussion

The more acidic pH values in surface water are due to the influence of soil leaching and riparian forest, which through organic decomposition releases humic and fulvic acids to these aquatic environments [35, 36, 37,38]. In the Caeté (Bragança) and Arari (Marajó Island) rivers in the Pará State-Brazil and other Amazonian rivers such as Solimões and Purus, in the Amazonas State, the values of pH and temperature were similar to those recorded in the rivers Arienga and Murucupí, with variations of 3.8 to 7.0 and 25 to 34 °C respectively[30, 39, 40, 38]. The temperature of the surface waters in the Amazonian environments oscillates according to the thermal amplitude of daily and seasonal, being able to vary according in the depth of the river and time of day, with possibility of affecting the characteristics physical, chemical and biological of the aquatic ecosystem[38] (Alves et al., 2012). The study in the water bodies of Malawi in East Africa pointed to the influence of industrial effluent discharges, with pH values between 6.3 and 7.5 [40], similar to the surface waters of the Murucupí River, which were also impacted by domestic and industrial sewage [41].

The highest values of these variables were determined in the Murucupí River, indicating a higher presence of dissolved solids, possibly due to greater anthropic influence through the launching of sewage and deforestation in areas near to its banks. The transport of solid materials in different aquatic environments influences in the rates and types of chemical, biological processes and geomorphic

Table 2. Descriptive statistics of the physical-chemical variables determined in the Arienga River in 2011.

				Rainy Season				Dry Season		
Physicochemical Variables	Unit	N	Tide	x̄ ±SD	Maximum	Minimum	N	x̄ ±DP	Maximum	Minimum
Temperature	°C	12	Ebbing	27±1.16	29	25	12	28±1.24	30	26
		12	Flooding	26±1.31	29	25	12	28±1.47	31	26
pH	-	12	Ebbing	5.76±0.82	6.75	4.77	12	5.55±0.64	6.47	4.79
		12	Flooding	5.70±0.92	7.21	4.75	12	6.25±0.94	7.33	4.87
Electric Conductivity	$\mu S.cm^{-1}$	12	Ebbing	22±9.61	37	13	12	21±13.33	48	7
		12	Flooding	21±10.24	42	13	12	25±16.40	49	4
Total Dissolved Solids	$mg.L^{-1}$	12	Ebbing	11±4.73	18	7	12	11±5.79	22	6
		12	Flooding	11±5.20	21	7	12	13±8.23	26	2
Dissolved Oxygen	$mg.L^{-1}$	12	Ebbing	5.21±0.64	6.45	4.40	12	6.29±1.17	7.98	4.44
		12	Flooding	5.88±0.63	7.16	5.19	12	6.24±0.77	7.83	5.34
BOD	$mg.L^{-1}$	12	Ebbing	14±3.48	19	9	12	10±2.75	16Physico chemical Variables	6
		12	Flooding	11±3.03	16	8	12	9±2.41	14	5
Ammoniacal-N	$mg.L^{-1}$	12	Ebbing	0.062±0.021	0.101	0.037	12	1.496±1.646	6.336	0.118
		12	Flooding	0.340±0.314	1.032	0.026	12	1.090±1.689	6.233	0.014
Nitrite-N	$mg.L^{-1}$	12	Ebbing	0.019±0.008	0.033	0.008	12	0.028±0.012	0.057	0.011
		12	Flooding	0.040±0.037	0.121	0.003	12	0.080±0.097	0.334	0.005
Nitrate-N	$mg.L^{-1}$	12	Ebbing	0.075±0.063	0.192	0.019	12	0.679±1.352	4.818	0.009
		12	Flooding	0.266±0.245	0.808	0.021	12	0.490±0.659	2.226	0.035
Phosphate	$mg.L^{-1}$	12	Ebbing	0.097±0.036	0.152	0.023	12	0.117±0.062	0.239	0.055
		12	Flooding	0.066±0.044	0.190	0.014	12	0.064±0.029	0.140	0.032
Sulfate	$mg.L^{-1}$	12	Ebbing	0.666±0.618	1.570	0.109	12	0.812±0.929	2.519	0.029
		12	Flooding	0.775±0.626	1.547	0.110	12	1.347±1.479	4.886	0.011
Total Hardness	$mg.L^{-1}$	12	Ebbing	2.899±2.220	6.331	0.481	12	4.765±3.263	14.389	2.301
		12	Flooding	2.823±1.989	5.377	0.232	12	5.824±3.498	14.389	1.146

N: Number of data pertaining to six (06) sampling points, with 12 data for each seasonal period; : Average; SD: Standard Deviation.

Table 3. Descriptive statistics of the physicochemical variables determined in the Murucupí River in 2011.

Physicochemical Variables	Unit	N	Tide	Rainy Season			N	Dry Season		
				$\bar{x}$ ±SD	Maximum	Minimum		$\bar{x}$ ±DP	Maximum	Minimum
Temperature	°C	14	Ebbing	28±0.62	29	27	14	30±0.99	32	28
		14	Flooding	28±0.52	28	27	14	30±0.88	32	29
pH	-	14	Ebbing	6.22±0.33	6.6	5.51	14	6.61±0.49	7.23	5.54
		14	Flooding	6.19±0.47	7.12	5.51	14	6.71±0.48	7.3	5.54
Electric Conductivity	$\mu S.cm^{-1}$	14	Ebbing	38±5.02	45	30	14	83±33.14	122	43
		14	Flooding	40±6.83	48	25	14	80±32.34	119	42
Total Dissolved Solids	$mg.L^{-1}$	14	Ebbing	19±2.70	23	15	14	38±15.51	57	19
		14	Flooding	20±3.44	24	12	14	37±15.01	56	19
Dissolved Oxygen	$mg.L^{-1}$	14	Ebbing	4.70±1.09	6.55	1.95	14	3.86±1.68	6.18	1.17
		14	Flooding	4.08±1.03	5.4	1.46	14	4.52±1.24	6.06	2.33
BOD	$mg.L^{-1}$	14	Ebbing	15±5.25	26	7	14	12±2.24	15	7
		14	Flooding	10±2.95	17	6	14	9±1.27	11	7
Ammoniacal-N	$mg.L^{-1}$	14	Ebbing	0.283±0.507	2.021	0.027	14	0.248±0.170	0.684	0.021
		14	Flooding	0.273±0.235	0.776	0.025	14	0.392±0.209	0.770	0.026
Nitrite-N	$mg.L^{-1}$	14	Ebbing	0.121±0.112	0.406	0.025	14	0.072±0.047	0.164	0.011
		14	Flooding	0.050±0.042	0.135	0.012	14	0.047±0.053	0.168	0.001
Nitrate-N	$mg.L^{-1}$	14	Ebbing	0.791±0.649	2.346	0.168	14	1.025±1.004	3.510	0.033
		14	Flooding	1.247±1.039	3.368	0.294	14	1.168±1.336	4.201	0.025
Phosphate	$mg.L^{-1}$	14	Ebbing	0.109±0.034	0.169	0.056	14	0.136±0.067	0.275	0.059
		14	Flooding	0.176±0.035	0.278	0.123	14	0.187±0.081	0.313	0.057
Sulfate	$mg.L^{-1}$	14	Ebbing	2.137±1.061	5.293	1.063	14	1.743±0.925	3.550	0.897
		14	Flooding	2.474±1.241	5.367	1.188	14	1.992±0.935	3.983	1.027
Total Hardness	$mg.L^{-1}$	14	Ebbing	3.415±1.170	5.311	1.241	14	8.769±4.962	18.568	1.832
		14	Flooding	3.101±1.291	4.671	0.112	14	8.186±5.694	17.731	1.792

N: Number of data pertaining to seven (07) sampling points, with 14 data for each seasonal period; $\bar{x}$: Average; SD: Standard Deviation.

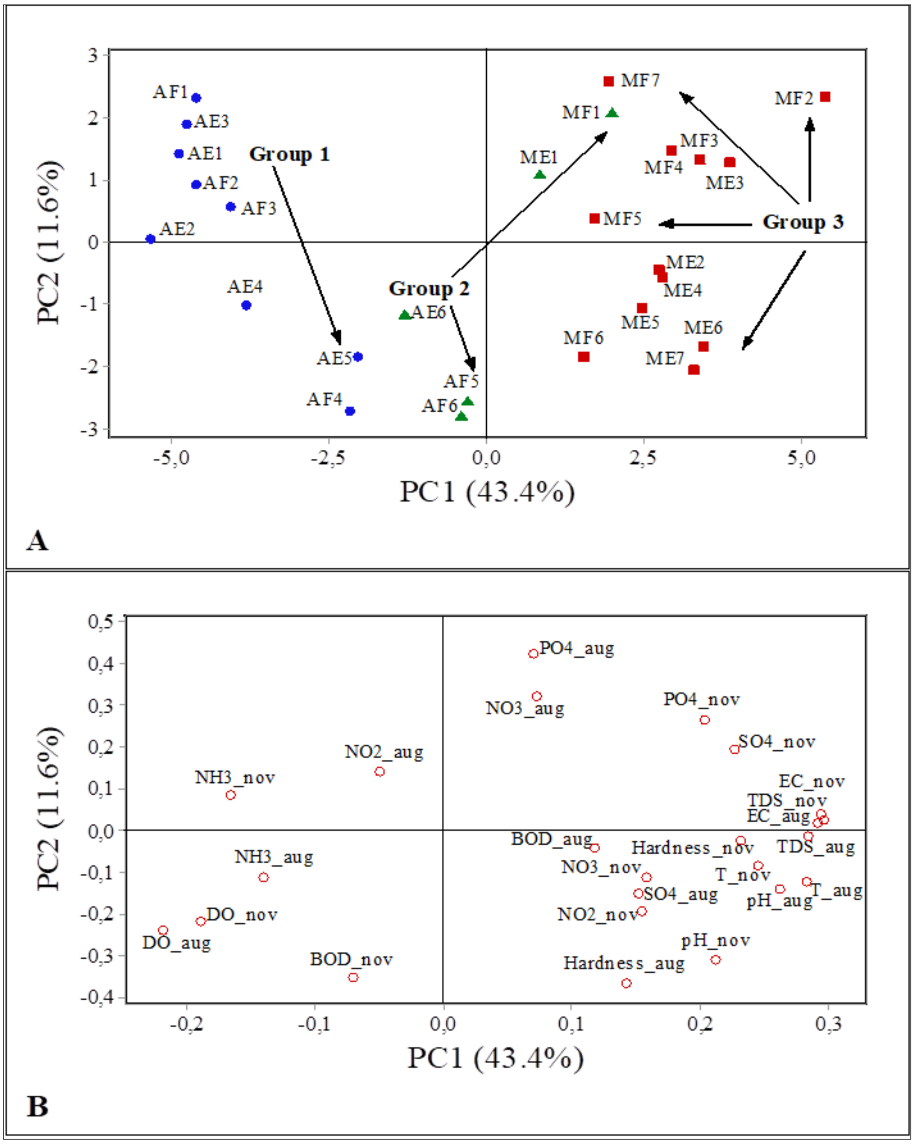

Figure 3. Analysis of main components of score plot type (A) and loading plot (B) on the data of the variables determined in the dry period (August and November) under ebbing and flooding tide and conditions in 2011. Note: AE (Arienga ebbing tide); AF (Arienga flooding tide); ME (Murucupí ebbing tide); MF (Murucupí flooding tide).

transformations[42, 43]. As example of these different characteristics, it is observed the values of electrical conductivity in the waters of the Solimões and Purus rivers and their tributaries which had variations from 0.02 to 26.4 µS.cm-1 in the black waters and from 47 to 122.4 µS.cm-1 in the white waters[31]. In the Maracanã River, northeast Pará State-Brazil, TDS values ranged from 10 to 28 mg.L-1 in distinct seasonal periods and in the Madeirinha and Acará rivers on the left bank of the Madeira River in Amazonas State, this variation was 14.2 to 74.2 $mg.L^{-1}$ [44, 45].

The concentrations of DO were higher in the waters of the Arienga River, while the Murucupí River presented less oxygenated water, a fact that can be explained by the greater amount of organic matter in this river due to the release of domestic sewage, biochemical decomposition of organic matter and respiration by the aquatic ecosystem contribute to the reduction of dissolved oxygen in water [46]. Other studies corroborate this information, for example, DO values in water bodies located in the island of Marajó-PA ranged from 2.98 to 5.29 $mg.L^{-1}$ in the rainy season and 2.59 to 5.88 $mg.L^{-1}$ in the dry season, the authors consider that the dynamics of this gas in aquatic ecosystems is related to its non-conservative behavior, for example, the decrease of water levels of the rivers in the dry season and the introduction of semidiurnal tides favors the increase of the concentration of dissolved oxygen in surface waters[38]. Similar values of DO were also recorded in other rivers in Brazil, such as the case of the Cachoeira River in the Bahia State, with values between 4.1 and 7.7 $mg.L^{-1}$ and higher values in the Turvo Limpo River in Minas Gerais State, that oscillated between 7.7 and 9.1 $mg.L^{-1}$ [47, 48].

The Arienga and Murucupí rivers had a similar distribution in relation to the BOD concentration, the highest records occurred in the rainy season, this fact may be related to the greater amount of organic matter introduced through resuspension processes or by action of the high tides that flooding the river banks, as well as the discharge of domestic sewage in the region [38]. The concentrations of BOD in the rivers Arienga and Murucupí had similar behavior to the waters of the Parauapebas River, southeastern Pará State-Brazil, the BOD values varied 2.2 and 9.79 mg.L-1 with largest records at points closest to the urban center where the discharges of effluent are more intense [49]. Turvo Limpo River in Minas Gerais State presented higher values with ranging from 13.3 to 411 mg.L-1, for the authors of this study, high BOD values may be related to the presence of large amounts of biodegradable biomass and discharge of domestic effluents in the hydrographic basin [48].

The Arienga River presented a distinct behavior in relation to the maximum values of ammonia nitrogen, nitrite and nitrate, with higher concentrations observed in the dry season, while in the Murucupí river, the maximum values were similar between the seasonal periods. The Arienga River may have been influenced by diffuse sources of natural or anthropogenic origin and the Murucupí River most likely suffered greater influence of domestic sewage besides the particulate material leached through rains. In aquatic ecosystems of the Brazil is perceived great anthropic influence, mainly in the dissolved inorganic forms, with emphasis of ammonia nitrogen and nitrate, a reality observed in this study. Table 4 shows the values of the nitrogen forms determined in the aquatic ecosystems of different regions of Brazil.

Phosphate concentrations were similar in the Arienga and Murucupí rivers, with higher values in the dry period, but without great variations. Values close to those recorded in the present study were observed in other rivers in Brazil, such as the phosphate values recorded in the Tibagi River between 0.02 and 0.35 $mg.L^{-1}$, Paraná State[51]. The concentration of phosphate near the discharge of industrial effluents in the Igarapé Curuperê River in the municipality of Barcarena-Pará reached 0.220 $mg.L^{-1}$, with values recorded in the margins of this water body varying between 0.050 $mg.L^{-1}$ and 0.175 $mg.L^{-1}$. In all evaluated extension of this water body, the variations were from 0.062 $mg.L^{-1}$ to 0.430 $mg.L^{-1}$ at ebbing tide and from 0.124 $mg.L^{-1}$ to 0.290 $mg.L^{-1}$ in the flood tide. In the same area of study, in the Igarapé Dendê, values ranging from 0.010 $mg.L^{-1}$ to 0.182 $mg.L^{-1}$ were recorded at ebb tide and from 0.050 to 0.110 $mg.L^{-1}$ in the flooding tide[52]. Among the main factors responsible for the increase of phosphate in surface water are the releases of domestic and industrial waste, therefore, the mainly responsible

Table 4. Ammonia nitrogen, nitrate and nitrite, values in Brazilian waters.

Author	Season/Year	Ammonia ($mg.L^{-1}$)	Nitrite ($mg.L^{-1}$)	Nitrate ($mg.L^{-1}$)	Water Body/Location
Horbe et al. (2005)[30]	RAINY (1998)	0.12 – 0.29	< LD	0.02 – 0.16	Igarapé Água Branca/ Amazonas State
	DRY (1998)	0.10 – 1.10	< LD	0.01 – 0.51	Puraquequara River/ Amazonas State
Richter et al. (2007)[53]	N.I (2002/2003)	0.3 – 33.8	N.A	0.80 – 2.70	Sistema Guarapiranga SP
Jordão et al. (2007)[48]	DRY (2005)	2.8 – 28	N.A	0.8 – 7.4	Turvo Limpo River/ Minas Gerais State
Pinto et al. (2009)[37]	RAINY (2003)	0.32 – 0.49	< LD	N.A	Igarapé Tarumã and Porto da Ceasa/ Amazonas State
		1.12 – 9.25	0.01 – 8.23	N.A	Igarapés São Raimundo and Educandos/ Amazonas State
Aguiar Netto (2013)[50]	DRY and RAINY (2005/2006)	< LD – 1.08	< LD – 0.08	0.02 – 1.04	Poxim River/Sergipe State

N.I: Not Informed; <LD: Less Than Limit of Detection; N.A: Not Analyzed.

for levels of phosphate in aquatic environments[47,51].

The Arienga and Murucupí rivers presented similar concentrations of sulfate in their waters, however, their highest values were recorded in different periods. The highest concentrations in the Arienga river occurred in the dry period, while in the Murucupí river the maximum values were found in the rainy season. Sulphate concentrations in the two rivers were close to those reported by other authors in studies in Brazil, in most cases the presence of sulfate is related to the geology of the sites, such as those observed in rivers affluent to the rivers Solimões and Purus, with averages of 5.2 $mg.L^{-1}$ and 7.7 $mg.L^{-1}$, while in the Solimões and Purus rivers the averages were 7.1 $mg.L^{-1}$ and 5.8 $mg.L^{-1}$ (31). Other authors reported variations from 1.30 $mg.L^{-1}$ to 26.5 $mg.L^{-1}$ in the Guarapiranga system in São Paulo and from 0.00 $mg.L^{-1}$ to 12.60 $mg.L^{-1}$ in two rivers of the Federal District. Brazil [53,54].

In another study on the Murucupí river, hardness ranged from 11 $mg.L^{-1}$ to 21 $mg.L^{-1}$ and according to the author, hardness concentrations are typical of the region and the fact that the highest concentrations are found in the period Dry is related to the intrusion of brackish waters of the Marajó Bay in the Barcarena estuarine system[55]. In the Água Branca stream, mean values of hardness of 0.40 $mg.L^{-1}$ were recorded in the rainy season and of 0.29 $mg.L^{-1}$ in the dry period and in the Puraquequara stream, the average found was 0.46 $mg.L^{-1}$ [30].

In study in the Ocoí River basin it was used the Principal Component Analysis (PCA), starting from obtained results found that diffuse sources of pollution were more evident and predominant in the rainy season[56]. The PCA also was used to evaluate the water quality of the Tibagi River in Ponta Grossa, allowed to observe the level of deterioration through point and diffuse sources near the industrial district of the city[57]. Other study carried in 2007 used this statistical tool to verify if the waters of the Tarumã-Açú River was polluted with the residues of the sanitary landfill near of this hydrographic basin and found that a differentiation in water quality occurred between the points sampled, well as they said that the water body was still able to reduce the impact of the sanitary landfill[58]. In aquatic systems studied in northern Greece, multivariate analysis helped identify four groups with different physicochemical characteristics and pollution levels[59]. Likewise, PCA significantly helped in the identification of similar and different quality groups in the extensions of the water bodies evaluated in this study.

Conclusion

The variables studied in these water bodies have their concentrations with well-defined trends in relation to rainfall and variation in physicochemical characteristics in the extensions evaluated, either by the action of natural or anthropogenic agents. This environmental behavior is clearly observed for the variables temperature, pH and dissolved oxygen, which presented very similar characteristics in the two rivers, that is, lower values in their sources and increase in the mouths.

From the multivariate analysis, it can be said that there is a physicochemical difference between the Arienga and Murucupí rivers, where it was possible to observe that the Murucupí River presented higher concentrations for most of the physical-chemical variables analyzed in relation to the Arienga river, indicating that the Arienga River may be more influenced by local geology, while in the Murucupí river both geology and anthropic factors are responsible for its physicochemical characteristics was visualized lower anthropic influence in surrounding of Arienga River, however, demand of the tourists in leisure areas during the dry season may have influenced the levels of nitrogen matter introduced in this water body. The information generated in this study allows us to say that the Murucupí river suffered a greater anthropogenic influence, mainly due to the domestic sewage released in this water body without due treatment, as well as other adjacent contributions that provided different physicochemical characteristics for these waters. The industrial activities developed in this region and other anthropogenic contributions have already caused great damage to certain environmental compartments, among them, the water bodies, through recurrent industrial waste leaks and untreated sewage launching. This information on the physicochemical characteristics of the rivers studied will serve for population, competent authorities and the scientific community in order to take more detailed measures and studies to evaluate the risk factors environmental and population health in region.

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References

1. Shil'krot G.S., Yasinskii S.V. (2002). Spatial and temporal variability of biogenic elements flow and water quality in a Small River, Moscow, Russia. Water Resources, 29, 312-318.
2. Stamatis G., Gartzos E. (1999). The silica supersaturated waters of northern Evia and eastern central Greece. Hydrological Processes, 13, 2833-2845.
3. Kelepertsis A., Alexakis D., Kita I. (2001). Environmental geochemistry of soils and waters of Susaki area, Korinthos, Greece. Environmental Geochemistry and Health, 23, 117-135.
4. Appelo C.A.J., Postma D. (2005). Geochemistry, groundwater and pollution. Leiden, New York: Balkema, 2ª Ed. 649 p.
5. Lambrakis N. (2006). Multicomponent heterovalent chromatography in aquifers. Modelling salinization and freshening phenomena in field conditions. Journal of Hydrology, 323, 230-243.
6. Stamatis G., Lambrakis N., Alexakis D., Zagana E. (2006). Groundwater quality in eastern Attica (Greece). Hydrological Processes, 20, 2803-2818.
7. Bathrellos G.D., Skilodimou H.D., Kelepertsis A., Alexakis D., Chrisanthaki I., Archonti D. (2008). Environmental research of groundwater in the urban and suburban areas of Attica region, Greece. Environmental Geology, 58, 11-18.
8. Alexakis D. (2008). Geochemistry of stream

sediments as a tool for assessing contamination by arsenic, chromium and other toxic elements: East Attica region, Greece. European Water, 21 (22), 57-72.

9. Palma P., Alvarenga P., Palma V., Fernandes R.M., Soares A.M.V.M., Barbosa I.R. (2010). Assessment of anthropogenic sources of water pollution using multivariate statistical techniques: A case study of the Alqueva's reservoir, Portugal. Environmental Monitoring and Assessment 165, 539-552.
10. Saeedi M., Abessi O., Sharifi F., Meraji H. (2010). Development of groundwater quality index. Environmental Monitoring and Assessment, 163 (1-4), 327-335.
11. Suthar S., Sharma J., Chabukdhara M., Nema A.K. (2010). Water quality assessment of river Hindon at Ghaziabad, India: Impact of industrial and urban wastewater. Environmental Monitoring and Assessment, 165,103-112.
12. Namaghi H.H., Karami G.H., Saadat S. (2011). A study on chemical properties of groundwater and soil in ophiolitic rocks in Firuzabad, east of Shahrood, Iran: With emphasis to heavy metal contamination. Environmental Monitoring and Assessment, 174, 573-583.
13. Pathak S.P., Kumar S., Ramteke P.W., Murthy R.C., Bhattacherjee J.W., Gopal K. (1994). Potability of water sources in relation to metal and bacterial contamination in some northern and northern-eastern districts of India. Environmental Monitoring and Assessment, 33, 151-160.
14. Cotta J.A.O., Rezende M.O.O., Piovani M.R. (2006). Avaliação do teor de metais em sedimento do rio Betari no Parque Estadual Turístico do Alto Ribeira-PETAR, São Paulo, Brasil. Quimica Nova, 29 (1), 40-45.
15. Jardim F.A., Resende R.M.S., Ladeia M.M., Giani A., Cerqueira D.A., Jardim B.F.M. (2008) Cyanobacteria blooms in waters of river intake areas in Minas Gerais – Brazil, during the dry season of 2007 – Contingency Plants. In: Simpósio Ítalo-Brasileiro de Engenharia Sanitária e Ambiental. Florença (Itália).
16. Belo A., Quináia S.P., Pletsch A.L. (2010). Avaliação da Contaminação de Metais em Sedimentos Superficiais das Praias do Lago De Itaipu. Quimica Nova, 33 (3), 613-616.
17. Instituto Internacional de Educação do Brasil-IEB (2012). Position of the Pro-Forum Civil Society Network in Barcarena: For a Just, Democratic and Sustainable Barcarena. 62 p. http://www.iieb.org.br/index.php/publicacoes/livros/posicionamento-da-rede-da-sociedade-civil-pro-forum-em-barca/
18. Instituto Evandro Chagas-IEC (2008). Relatório Técnico. Interações de vigilância ambiental em saúde na área industrial e portuária dos Municípios de Abaetetuba e Barcarena. Ananindeua-PA, 46 p. http//: iah.iec.pa.gov.br/iah/fulltext/pc/relatorios/barcarena2008.pdf.
19. Instituto Evandro Chagas-IEC (2009). Relatório técnico SAMAM 001: caracterização dos impactos ambientais, danos ao ecossistema e riscos a saúde decorrentes do lançamento no rio Murucupí de efluentes do processo de beneficiamento de bauxita, Barcarena-Pará. Ananindeua, PA, Brasil. 32 p [on line]. http://iah.iec.pa.gov.br/iah/fulltext/pc/relatorios/barcarena2009.pdf
20. Souza A.P.S., Lisboa R.C.L. (2006). Aspectos florísticos e taxonômicos dos musgos do município de Barcarena, Pará. Bol. Mus. Para. Emílio Goeldi. Ciências Naturais Belém, 1 (1), 81-104.
21. Instituto Brasileiro de Geografia e Estatística-IBGE (2017). Informações gerais sobre as cidades de Abaetetuba e Barcarena no Estado do Pará. http://cidades.ibge.gov.br/xtras/uf.php?coduf=15&search=para&lang=_EN
22. Porto L.J.L.S. (2009). Estudo da qualidade dos sedimentos de fundo do Rio Barcarena-PA. Dissertação de Mestrado. Universidade Federal do Pará. Centro de Geociências (geoquímica e petrologia), Belém-Pará, 91 p.
23. Instituto Nacional de Metereologia-INMET (2009). Banco de dados metereológicos para ensino e pesquisa (BDMEP). http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep
24. Marinha do Brasil (2011). Diretoria de Hidrografia e Navegação: Previsões de marés do porto de Vila do

Conde-PA. Centro de Hidrografia da Marinha. Banco Nacional de Dados Oceanográficos. http://www.mar.mil.br/dhn/chm/box-previsao-mare/tabuas/index.htm

25. Matta M.A.S. (2002). Fundamentos Hidrogeológicos para a Gestão Integrada dos Recursos Hídricos da Região de Belém/Ananindeua-Pará, Brasil. Tese de Doutorado. Ed. Universidade Federal do Pará. Centro de Geociências, Belém-Pará, 584 p.
26. Almeida F.M., Matta M.A.S., Prado J.B., Dias E.R.F., Bandeira IN, Figueiredo A.B., Brasil R.O. (2006). Análise geométrica e susceptibilidade à contaminação dos sistemas aquíferos da região de Barcarena/PA. XIV Congresso Brasileiro de Águas Subterrâneas.
27. Oliveira R.D. (2002). Zoneamento Agroambiental do Município de Barcarena-Pará. Dissertação de Mestrado. Faculdade de Ciências Agrárias do Pará, Belém-Pará, 220 p.
28. Souza APS, Lisboa RCL. (2005). Musgos (Bryophyta) na Ilha Trambioca, Barcarena, PA, Brasil. Acta bot. bras. 19 (3), 487-492.
29. Sioli H., Klinge H. (1962). Solos, típicos de vegetação e águas na Amazônia. Amazoniana, 1, 27-41.
30. Horbe A.M.C., Gomes I.L.F., Miranda S.F., Silva M.S.R. (2005). Contribuição à hidroquímica de drenagens no Município de Manaus – AM. Acta Amazônica, 35(2), 119-124.
31. Queiróz M.M.A., Horbe A.M.C., Seyler P., Moura C.A.V. (2009). Hidroquímica do rio Solimões na região entre Manacapuru e Alvarães-Amazonas-Brasil. Acta Amazônica, 39 (4), 943-952.
32. Conselho Nacional de Meio Ambiente-CONAMA (2005). Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o se enquadramento. Alterada pelas Resoluções 410/2009 e 430/2011. Diário Oficial da República Federativa do Brasil, Brasília, DF, 53, p. 58-63. http://www.mma.gov.br/port/conama/res/res05/res35705.pdf
33. American Public Health Association-APHA (2005). Standard methods for the examination of water and wastewater. 21th. ed. Washington, 1600 p.
34. United States Environmental Protection Agency-USEPA (2007). Method 9056A: determination of inorganic anions by ion chromatography. Revision 1, 19 pp. https://www.epa.gov/hw-sw846/sw-846-test-method-9056a-determination-inorganic-anions-ion-chromatography
35. Sioli H. (1985). Amazônia: fundamentos da ecologia da maior região de florestas tropicais. Ed. Petrópolis: Vozes. 72 p.
36. Esteves F.A. (1998). Fundamentos de limnologia. 2. Ed. Rio de Janeiro: Interciência, 602 p.
37. Pinto A.G.N., Horbe A.M.C., Silva M.S.R., Fonseca S.A., Miranda S.A.F., Pascoaloto D., Santos H.M.C. (2009). Efeitos da ação antrópica sobre a hidrogeoquímica do rio Negro na orla de Manaus/AM. Acta Amazônica, 39 (3), 627-638.
38. Alves I.C.C., El-Robrini M., Santos M.L.S., Monteiro S.M., Barbosa L.P.F., Guimarães J.T.F. (2012). Qualidade das águas superficiais e avaliação do estado trófico do Rio Arari (Ilha de Marajó, norte do Brasil). Acta Amazônica, 42 (1), 115-124.
39. Pereira L.C.C., Monteiro M.C., Guimarães D.O., Matos J.B., Costa R.M. (2010). Seasonal effects of wastewater to the water quality of the Caeté river estuary, Brazilian Amazon. Anais da Academia Brasileira de Ciências, 82 (2), 467-478.
40. Phiri O., Mumba P., Moyo B.H.Z., Kadewa W. (2005). Assessment of the impact of industrial effluents on water quality of receiving rivers in urban areas of Malawi. International Journal of Environmental Science and Technology, 2 (3), 237-244.
41. Medeiros A.C., Faial K.R.F., Faial K.C.F., Lopes I.D.S., Lima M.O., Guimarães R.M., Mendonça N.M. (2017). Quality index of the surface water of Amazonian rivers in industrial areas in Pará, Brazil. Marine Pollution Bulletin, 123, 156-164
42. Bolin B., and Cook R.B (1983). The major biogeochemical cycles and their interactions (Scope Report 21). United States: N. p., Web.
43. Mertes L.A.K., Smith M.O., Adams J. B (1993).

Estimating Suspended Sediment Concentrations in Surface Waters of the Amazon River Wetlands from Landsat Images. Remote Sensing of Environment, 43, 281-301.

44. Costa F.F., Lima W.N.L., Dias J.C. (2009). Avaliação hidrogeoquímica de áreas selecionadas na bacia hidrográfica do rio maracanã (nordeste do Pará). Holos Environment, 9 (2),167-182.
45. Horbe A.M.C., Queiroz M.M.A., Moura C.A.V., Toro M.A.G. (2013). Geoquímica das águas do médio e baixo rio Madeira e seus principais tributários - Amazonas - Brasil. IBGE, 43 (4), 489-504.
46. Janzen G. J, Schulz H. E., Lamon A. W (2008). Medidas da Concentração de Oxigênio Dissolvido na Superfície da Água. Revista de Engenharia Sanitária e Ambiental, 13, n.3.
47. Lucio M.Z.T.P.Q.L., Santos S.S., Silva D.M.L. (2012). Hydrochemistry of Cachoeira River (Bahia State, Brazil). Acta Limnologica Brasiliensia, 24 (2), 181-192.
48. Jordao C.P., Ribeiro P.R.S., Matos A.T., Fernandes R.B.A. (2007). Aquatic Contamination of the Turvo Limpo River Basin at the Minas Gerais State, Brazil. Journal of The Brazilian Chemical Society, 18 (1), 116-125.
49. Siqueira G.W., Aprile F., Miguéis A.M. (2012). Diagnóstico da qualidade da água do rio Parauapebas (Pará – Brasil). Acta Amazonica, 42 (3), 413-422.
50. Aguiar Netto A. O., Garcia C.A.B., Alves J.P.H., Ferreira R.A., Silva M.G. (2013). Physical and chemical characteristics of water from the hydrographic basin of the Poxim River, Sergipe State, Brazil. Environmental Monitoring and Assessment, 185, 4417-4426.
51. Bisinoti M.C., Yabe M.J.S., Gimenez S.M.N. (2005). Using principal component analysis to characterize the Tibagi River hydrographic basin, Paraná State, Brazil. Journal of Food, Agriculture and Environment, 3 (3 and 4), 153-160.
52. Lima M.O., Santos E.C.O., Jesus I.M., Medeiros A.C., Faial K.C.F., ALVES C.N. (2011). Assessment of Surface Water in Two Amazonian Rivers Impacted by Industrial Wastewater, Barcarena City, Pará State (Brazil). Journal of the Brazilian Chemical Society, 22 (8), 1493-1504.
53. Richter E.M., Fornaro A., Lago C.L., Agnes L (2007). Avaliação da composição química de águas do Sistema Guarapiranga: estudo de caso nos anos de 2002 e 2003. Quimica Nova, 30 (5), 1147-1152.
54. Muniz D.H.F., Moraes A.S., Freire I.S., Cruz C.J.D., Lima J.E.F.W., Oliveira-Filho E.C. (2011). Evaluation of water quality parameters for monitoring natural, urban, and agricultural areas in the Brazilian Cerrado. Acta Limnologica Brasiliensia, 23 (3), 307-317.
55. Pereira S.F.P., Lima M.A., Freitas K.H., Mescouto C.S., Saraiva A.F. (2007). Estudo químico ambiental do rio Murucupí-Barcarena, PA, Brasil, área impactada pela produção de alumínio. Revista Ambi-Água, 2 (3), 62-82.
56. Silva G.S., Silva G.S., Sousa E.R., Konrad C., Bem C.C., Pauli J., Pereira A. (2009). Phosphorus and nitrogen in waters of the Ocoí River Sub-basin, Itaipu Reservoir Tributary. Journal of The Brazilian Chemical Society, 20 (9), 1580-1588.
57. Zimmermann C.M. (2008). Avaliação da qualidade do corpo hídrico do rio tibagi na região de ponta grossa utilizando análise de componentes principais (PCA). Quimica Nova, 31 (7), 1727-1732.
58. Santana G.P., Barroncas P.S.R. (2007). Estudo de metais pesados (Co, Cu, Fe, Cr, Ni, Mn, Pb e Zn) na Bacia do Tarumã-Açu Manaus-(AM). Acta Amazonica, 37 (1), 111-118.
59. Simeonov V., Stratis J.A., Samara C., Zachariadis G., Voutsa D., Anthemidis A., Sofoniou M., Kouimtzis Th. (2003). Assessment of the surface water quality in Northern Greece. Water Research 37, 4119-4124.