Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Characterization of water quality and the effects of land use and seasonality on springs in eastern Amazonia

ARTICLES doi:10.4136/ambi-agua.2909

Received: 10 Mar. 2023; Accepted: 17 Jul. 2023

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ABSTRACT

Land-use changes followed by inadequate management may cause serious impacts to springs, generating losses in quality and availability. An alternative to minimize or mitigate potential future impacts is to monitor the water quality parameters of micro-watersheds in the medium- and long-term. This monitoring is essential for planning purposes and governmental environmental regulation, especially in highly altered regions in the Amazon, such as Paragominas, in the state of Pará. This study investigated the influence of land use change and seasonality on the quality of springs. For this purpose, physicochemical parameters characteristic of water quality in five collection points of springs with a surrounding area of distinct land use history were analyzed between 2015 and 2017. Following the current legislation, the only parameter in imbalance was dissolved oxygen (DO). However, these are common values, considering springs. The results showed that most of the parameters presented variation to different land uses. This interpretation was intensified mainly by the variations in Sodium, TN, DO and temperature. However, few of these variables were related to local seasonality (only turbidity, sulfate and potassium). These results prove that it is possible to integrate the change in the use and occupation of the basin, determined by the variations observed in the sampled points. Thus, studies and diagnostics that can subsidize management in basin areas are an important tool to direct public policies to improve environmental and social quality for the population living around these basins.

Keywords: Amazon, land use change, springs, water quality.

Caracterização da qualidade de água e os efeitos do uso da terra e sazonalidade em nascentes no leste da Amazônia

RESUMO

Mudanças de uso da terra seguido de manejo inadequado podem causar sérios impactos a nascentes, gerando prejuízos na qualidade e disponibilidade. Uma alternativa para minimizar ou mitigar impactos potenciais futuros é monitorar a médio e longo prazo os parâmetros de qualidade da água de microbacias. Este acompanhamento é essencial para fins de planejamento e regulamentação ambiental governamental, principalmente em regiões na Amazônia altamente alteradas, como em Paragominas, no estado do Pará. O objetivo deste estudo foi investigar a influência da mudança de uso da terra e da sazonalidade na qualidade de nascentes. Para isso, parâmetros físico-químicos característicos de qualidade da água em cinco pontos de coleta de nascentes com área circundante de histórico de uso da terra distintos foram analisadas entre 2015 e 2017. Seguindo a legislação vigente, o único parâmetro em equilíbrio foi o oxigênio consumido (OD). Entretanto, estes são valores comuns, considerando para nascentes. Os resultados mostraram que a maioria dos parâmetros apresentou variação em relação aos distintos usos da terra. Esta interpretação foi intensificada principalmente pelas variações encontradas em Sódio, NT, OD e temperatura. No entanto, poucas dessas variáveis foram relacionadas à sazonalidade local (apenas turbidez, sulfato e potássio). Estes resultados comprovam que é possível integrar a mudança no uso e ocupação da bacia, determinadas pelas variações observadas nos pontos amostrados. Assim, estudos e diagnósticos que possam subsidiar a gestão em áreas de bacias constituem importante ferramenta para direcionar políticas públicas de melhoria da qualidade ambiental e social para a população que vive no entorno destas bacias.

Palavras-chave: Amazônia, mudança do uso do solo, nascentes, qualidade da água.

1. INTRODUCTION

The Brazilian Amazon rainforest, despite being vital for maintaining biodiversity and hydrological and climatic cycles, has shown high and increasing rates of land-use change in recent years (Silva Jr. *et al.*, 2020; Smith *et al.*, 2021). Replacement of native forests with agricultural and forestry plantations is a continuous and growing trend, which is intensified in catchment areas, extending to the margins of water bodies, where water quality is negatively impacted (Hunke *et al.*, 2015). Because of land degradation and inadequate management, water resources face serious impacts, which results in damage to water quality and availability (Santos and Melo, 2017).

The critical scarcity of native vegetation cover around springs and the use of the nearby areas for pastures and crops, among other land use changes, can expose the soil to the action of rainwater, changing water quality (Wohl, 2017; Rodrigues *et al.*, 2003). On the other hand, the presence of riparian vegetation in the surroundings has the environmental function of preserving water resources (Almada *et al.*, 2019; Chase *et al.*, 2016) and biodiversity (Fierro *et al.*, 2021).

Seasonality and temperature, through the rainfall regime, are also important predictors that explain some of the variation in water quality parameters in the Amazon region. The increase or decrease in the volume of water and temperature, caused by rains or droughts, leads to a variation in some nutrient concentrations (Rodrigues *et al.*, 2003; Prado *et al.*, 2021). Changes in springs water quality associated with land use conversion have been demonstrated previously in the Amazon region (Figueiredo *et al.*, 2010; Mello *et al.*, 2018; Nóbrega *et al.*, 2018).

One approach to assessing and managing environmental impacts caused by land change and land use is to monitor water quality parameters, selecting those that may be embedded in the influence of land use and occupation (Rao *et al.*, 2017; Selvakumar *et al.*, 2017). Micro-watersheds monitoring, based on the information collected, leads to a better understanding of the true influences of each degradation process, in addition to the more effective possibility of managing and controlling these impacts. Source water quality is important, not only because it is highly influenced by the surrounding environment, but also because they are the first line of defense against potential contaminants such as excess fine sediment or nutrients and the first point of receipt of organic matter (Alexander *et al.*, 2007).

However, monitoring studies in this scientific scope, in a medium and long term, are essential, principally in tropical climatic basis (Barakat *et al*., 2018). Understanding how these land-use changes will affect the water functions of Amazonian rivers is important for minimizing or mitigating any potential adverse impacts and for the purposes of governmental environmental planning and regulations. Moreover, springs are important hydrologic and biogeochemical elements in landscapes because they connect the terrestrial environment with larger rivers (Figueiredo *et al.*, 2010) and more information on water quality in springs is needed (Hunke *et al*., 2015; Pereira Jr. *et al*., 2019).

In this context, the objective of this study was to evaluate the water quality of springs located in a highly altered Amazon region, and to investigate which factors may help explain it. For this, physical-chemical water parameters from five springs located in the municipality of Paragominas (PA) were quantified, evaluated, and correlated with the types of land use in their surroundings, and with the regional seasonality.

2. MATERIAL AND METHODS

2.1. Study area

The study area is in the municipality of Paragominas, eastern Pará state, Brazil (Figure 1). The climate of the region is classified as Monsoon (Am) according to Köppen's classification, with an average annual temperature of 26.3ºC and annual precipitation of 1,761 mm per year (Martorano *et al*., 2011). The rainfall distribution in the region is defined by the rainy season, from December to April, with monthly rainfall above 400 mm/month. The dry season extends from May to November, with values below 250 mm/month of precipitation (INPE; CPTEC, 2021).

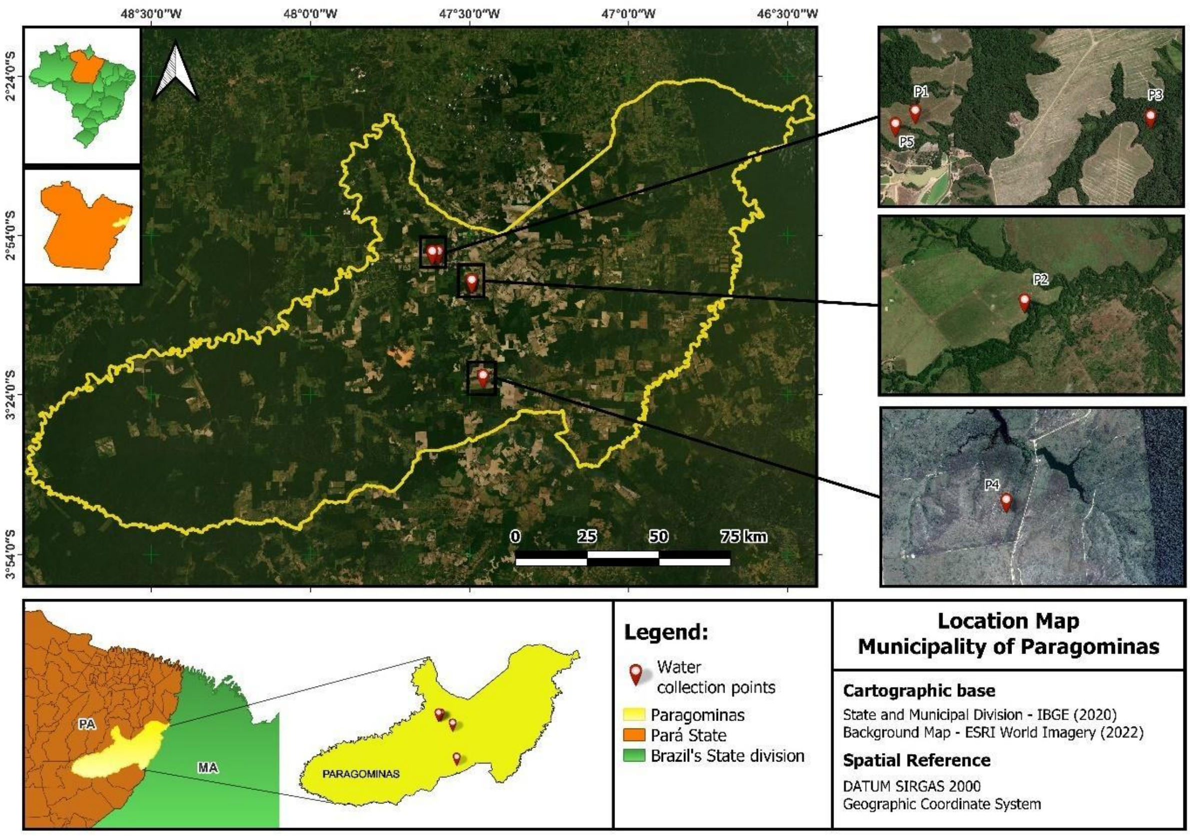

Figure 1. Study area. Distribution of sampling points in the water bodies (springs) studied in the municipality of Paragominas-PA, Brazil.

Paragominas municipality went through a series of economic cycles that drove several changes in land use over time. The occupation of the municipality began in the 1960s, with Belém-Brasília highway (BR-010). In the following years, the predominant land uses were slash and burn agriculture and cattle ranching (Uhl *et al.* 1988). From the 1980s to the 1990s, logging became the main economic activity (Uhl e Vieira, 1989; Verissimo *et al.*, 1992). From the 21st century on, land use change was aimed at economic diversification, which included the expansion of mechanized agriculture, improvements in livestock productivity, reduction of the impact of selective logging, mining, and reforestation with native and exotic species (Nunes, 2015). Data from 1985 to 2021 show loss trends of forest areas and non-forest natural formation, while over this period, areas of agricultural production only grow (Projeto Mapbiomas, 2022).

The drainage system, which extends throughout the municipality, has the Capim River and Gurupi River Basins as the main ones, which are subdivided along 54% and 46%, respectively, of the entire area of the municipality of Paragominas (Pereira Jr. *et al.*, 2019).

2.2. Water Sampling

Water sampling was performed at sampling points distributed in five different springs (Figure 1, Table 1) between October 2015 and October 2017. Table 1 also presents the description of the watershed areas upstream of each of the points. The basins were delimited based on the Digital Elevation Model - DEM provided by images from TOPODATA project of the National Institute for Space Research (INPE), using the tools available in Google Earth Engine and QGis, both available for free. Every two months over the years of monitoring (totaling 12 campaigns), one sampling was performed at each sampling point, considering the seasonality of the region (dry season n = 7; wet season n = 5), totaling 60 samples throughout the study. The sampling points of the evaluated water bodies, their qualitative characteristics of riparian vegetation and land use history are described in Table 1. These qualitative characteristics were acquired during the sampling campaigns. The samplings were always carried out in the morning (08h00 – 11h00 am GTM -3).

2.3. Physical-chemical parameters

Water sampling for obtaining physical-chemical parameters at each sampling point was performed in two stages. The first corresponded to *in situ* determinations using the ORION 115 probe. The parameters determined in this stage were: water surface temperature, dissolved oxygen (DO), and electrical conductivity (EC). The pH was also acquired at this stage, using a handylab1 pHmeter. Turbidity was determined by the PoliControl AP2000 turbidimeter.

The second stage was conducted at Hydrochemistry Laboratory of the Federal University of Pará (UFPA) to determine other water parameters, using titration methodologies (total nitrogen - TN) and the Dionex DX-120 ion chromatograph (sulfate, sodium, potassium, magnesium and calcium) (APHA *et al.*, 1998).

Sampling, measurement and storage methodologies followed the criteria and procedures based on Standard Methods for the Examination for Water and Wastewater (APHA *et al.*, 1995). For *in situ* measurements, when the sensors were not used directly in the springs, a sterilized glass bottle was used and later set to collect water from the springs. For laboratory analyses, the samples were preserved and packed in thermal boxes. The containers used were sterile bags suitable for collection. All equipment and chemical compounds for titration used in the study were calibrated before all campaigns. After obtaining the analyzed parameters, they were interpreted and compared with the limits established in the current legislation for Brazilian surface waters (CONAMA, 2005; 2008).

Table 1. Location of surface water sampling points (springs), visual characterization of riparian vegetation and their watersheds areas description, studied in Paragominas-PA, Brazil.

Sampling Point	Coordinates	Predominant Cover	Riparian Vegetation Description	Watershed Catchment Area Description
P1	02°52'49.1" S 47°33'39.2" W	Pasture	The riparian vegetation area is considerably reduced, being only 5 meters wide near the sampling point. The water body is three meters wide at the sampling point.	Predominantly composed of areas of forest formations, areas of temporary crops, mainly soybeans, and areas of pasture. There is still the occurrence of small areas occupied by grassland.
P2	02°58'11.4" S 47°26'13.2" W	Temporary Crop (Soybean)	The soybean cultivation was preceded by pasture, which remained in the area for 25 years. The riparian vegetation of this system shows signs of degradation. Erosion points can be observed.	Predominance of areas of temporary crops, with some occurrences of wetlands and grassland, but with a considerable presence of urbanized areas.
P3	02°52'50.6" S 47°32'32.8" W	Temporary Crop (Soybean/Corn)	Soybean/corn cultivation was preceded by pasture, which remained in the area for 30 years. This system has dense riparian vegetation.	Area with a distribution of uses very similar to those found in the area referring to point 1, with a predominance of forest formations sharing space with temporary crops.
P4	03°16'08.0" S 47°24'05.8" W	Silviculture	Forestry system with alternated plantation of Paricá (*Schizolobium amazonicum*) and Eucalypt (*Eucalyptus* spp.). The riparian vegetation was completely deforested and reforested in 2009, with actual length of 35 meters in the evaluated years.	Area with greater presence of forest formations, followed by areas of soybean cultivation.
P5	02°52'52.8" S 47°33'44.8" W	Secondary Forest	Secondary forest, 65 cm long, with a large supply of litter in and around its bed. This sampling point represents our control area.	As with the area observed in point 1, there is a greater occurrence of forest formations, followed by areas of pasture and temporary crops, in addition to small areas of flooded fields around water bodies.

2.4. Pluviometric data

Seasonality was represented by monthly precipitation data between 2015 to 2017, acquired by INMET automatic station databases (National Institute of Meteorology - Station A212, Paragominas) (INMET, 2023). This database is captured hourly. For the study, monthly precipitation data were acquired by the sum of precipitation of all days of the month campaign.

2.5.Data analysis

Initially, the mean and standard deviation of water attributes were described and presented by seasonality and collection points, as shown in Table 2 and Figure 2. Subsequently, we investigated which factors contribute to explain the springs water quality. Each water quality parameter was compared individually between sample points (land use) and seasonality, separately, over the years.

Each response variable was checked for normality hypothesis test (Shapiro – Wilk) and transformed, when necessary, using a logarithmic transformation, indicating which of these followed a normal distribution from significance levels greater than 0.05. Only DO, showed a normal distribution after data transformation.

The parameters that showed normal distribution were followed by the analysis of variance test (Anova – *One way*) and later with Tukey's *post hoc* multiple comparisons test. The non-parametric Kruskal Wallis test was used for the other data, followed by Dunn's multiple comparison test. Both comparisons of means considered the 95% confidence interval.

To check the relationship between water parameters and seasonality (monthly precipitation values), correlation, which shows the degree of linear association, was calculated between them, and measured by the degree of correlation as a coefficient (R) (Figueiredo *et al.*, 2010). The value of R ranges from -1 to +1, representing negative and positive correlation, respectively.

The analyses were performed in R software (version 4.0.1). We used dplyr packages (Wickham *et al.*, 2019) for data cleaning and manipulation. For Anova, we used the *aov* function in the *stats* package (Chambers *et al.*, 1992) and for the Tukey test, we used the *TukeyHSD* function in the *agricolae* package (De Mendiburu, 2019). For Kruskall Wallis, we applied the *Kruskal.test* function in the *stats* package (Hollander *et al.*, 2013) and for Dunn's test we applied the *dunnTest* function in the *FSA* package (Dunn, 1964). The acquisition of graphs was possible using the *ggplot2* functions (Wickham, 2014). Finally, the correlation analysis with precipitation was performed using the *cor.test* function within the *stats* package.

3. RESULTS AND DISCUSSION

3.1. Physical-chemical characteristics of water bodies

The arithmetic means and standard deviations are presented in Figure 2 and Table 2 for each water parameters of the 12 collection campaigns in the five sampling points. When comparing the results of physical-chemical parameters with the limits defined by current legislations that establish classification of water bodies (CONAMA, 2005; 2008), almost all water quality variables are below the maximum limits allowed (Table 2). The only parameter in imbalance was dissolved oxygen (DO), with average values below any classification of freshwater water bodies in springs P3, P4 and P5, and with Class 2 classification for the spring P1 and Class 3 classification for the spring P2 (Table 2). Although these values are low and below the minimum legal limits, dissolved oxygen values like these are common, considering groundwater values (Rose and Long, 1988).

Table 2. Arithmetic means and standard deviation of the parameters analyzed in the 12 campaigns, discriminating the periods of wet and dry seasons, in five water bodies (springs) sampled in the municipality of Paragominas, Pará, Brazil. Mean values followed by the same letter do not differ statistically throughout the study, following Tukey's test ($p < 0.05$).

Water Parameter	P1		P2		P3		P4		P5	
	Pasture		Crop1		Crop2		Silviculture		Secondary Forest	
	wet	*dry*	*wet*	*dry*	*wet*	*Dry*	*wet*	*dry*	*wet*	*dry*
pH	5.81 a	5.66 a	5.24 a	5.07 a	4.77 a	5.01a	4.89 a	4.9 a	5.3 a	5.36 a
	±1.12	±0.71	±0.40	±0.31	±0.53	±0.56	±0.17	±0.53	±0.83	±0.80
EC	37.7 b	45.04 b	49.08 a	42.94 a	48.14 ab	102.6 ab	40.14 a	52.21 a	34.34 ab	49.94 ab
(μScm^{-1})	±5.70	±8.27	±6.65	±8.67	±4.00	±82.10	±11.13	±17.85	±13.80	±16.77
DO	4.55 a	4.61 a	2.96 b	2.22 b	2.11 b	1.58 b	1.44 b	1.79 b	2.61 b	1.41 b
($mg\ L^{-1}$)	±0.20	±1.16	±1.80	±1.82	±1.24	±1.26	±0.82	±1.13	±1.06	±1.21
Turb *	116.37 a	11.03 a	47.46 a	18.1 a	80.88 a	29.77 a	7.8 a	8.98 a	45.27 a	12.94 a
(NTU)	±201.39	±10.11	±30.91	±9.61	±163.30	±49.01	±12.23	±8.97	±36.07	±18.97
Temp	26.67 a	29.96 a	26.26 b	26.16 b	25.79 b	26.04 b	25.7 b	25.9 b	25.75 b	25.71 b
(°C)	±0.45	±3.97	±1.39	±1.52	±0.89	±0.34	±0.5	±0.31	±0.83	±0.79
TN	0.44 a	0.54 a	0.74 ab	0.53 ab	0.22 b	0.37 b	0.43 a	0.48 a	0.73 ab	0.6 ab
($mg\ L^{-1}$)	±0.06	±0.07	±0.12	±0.11	±0.11	±0.27	±0.07	±0.27	±0.09	±0.29
SO42- *	1.01 a	0.31 a	3.35 a	1a	0.72 a	0.68 a	0.81 a	0.28 a	1.35 a	0.71 a
($mg\ L^{-1}$)	±0.62	±0.29	±2.28	±1.48	±0.44	±1.04	±0.47	±0.39	±0.34	±0.7
Na1+	1.41 a	2.14 a	2.15 c	2.2 c	3.77 ab	2.8 ab	1.64 c	2.16 c	0.65 b	1.57 b
($mg\ L^{-1}$)	±0.42	±0.40	±0.70	±0.17	±1.42	±1.68	±0.96	±0.99	±1.03	±0.75
K1+ *	0.86 a	0.71 a	2.24 a	0.56 a	1.08 a	0.44 a	0.84 a	0.57 a	0.23 a	0.48 a
($mg\ L^{-1}$)	±0.36	±0.74	±0.65	±0.54	±0.89	±0.45	±0.53	±0.79	±0.32	0.38
Mg2+	0.13 a	0.38 a	0.38 a	0.38 a	0.28 a	0.46 a	0.09 a	0.26 a	0.21 a	0.37 a
($mg\ L^{-1}$)	±0.18	±0.25	±0.52	±0.33	±0.38	±0.40	±0.15	±0.18	±0.15	±0.26
Ca2+	0.35 a	0.46 a	0.71 a	0.39 a	1.17 b	0.98 b	0.15 b	0.15 b	0.34 a	0.3 a
($mg\ L^{-1}$)	±0.42	±0.46	±0.90	±0.25	±0.82	±0.61	±0.00	±0.02	±0.29	±0.26

*Parameters that showed seasonal variation throughout the study based on correlation test ($p < 0.05$).

Despite the hydrological importance of springs, few studies in the region give us support to compare the results in this study. Nonetheless, Figueiredo *et al.* (2010) showed similar values of EC and pH in low-order streams in Paragominas municipality, as Pacheco Jr. *et al.* (2005) present similar data for EC, Sodium, pH and Calcium, compared to our results. The same occurred for EC and Turbidity in Pereira Jr. *et al.* (2019) when analyzing physical, chemical and microbiological aspects, in Paragominas rivers with higher orders in the process of urban expansion.

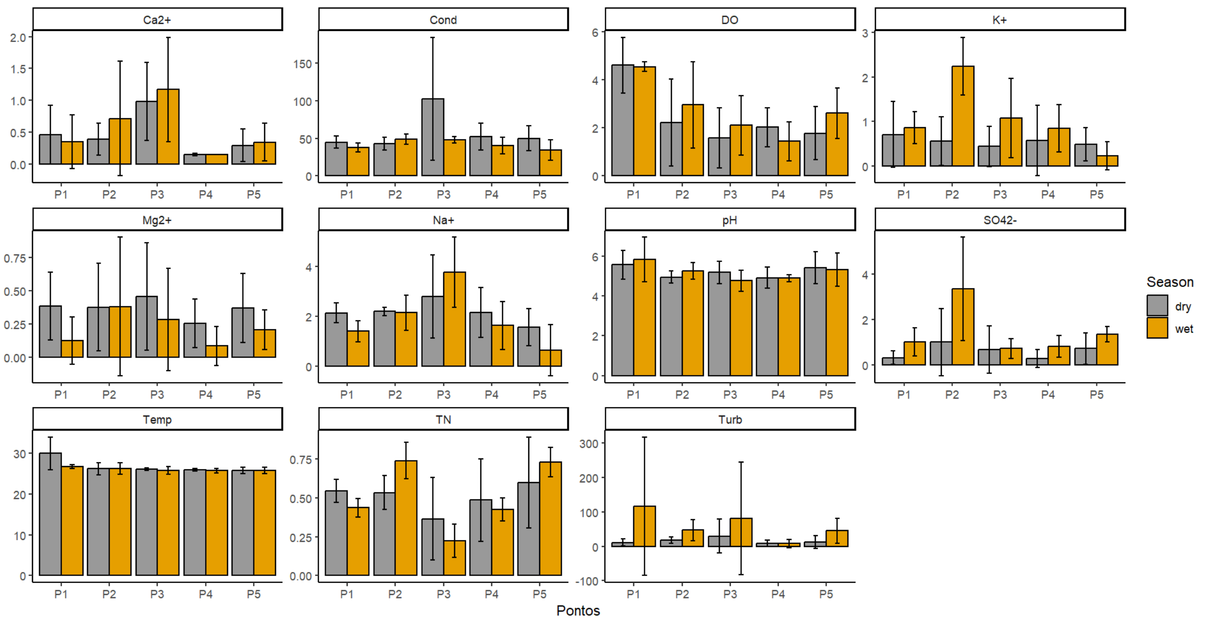

Figure 2. Mean and standard error of physical-chemical parameters of springs studied, considering seasonality, between the years 2016 and 2017. Where: P1 = Pasture; P2 = Crop1; P3 = Crop2; P4 = Silviculture; P5 = Secondary Forest.

3.2. Relationship between environmental aspects and water quality

In addition to the characterization of water quality, our objective in this research was to investigate the influence of land use change and seasonality on the quality of springs, represented by a highly altered region. For explanatory factors investigation, Table 3 shows the results of multiple comparison tests statistical tests. The results showed that, separately, most of the water quality parameters varied along the collection points analyzed. However, few of these variables were related to local seasonality, only turbidity, sulfate and potassium (Table 3).

Despite different land use histories, there was no distinction in pH concentrations among the collection points studied. Natural factors such as rock dissolution and pedogenesis affect pH (Von Sperling, 2007). It is noteworthy that most of the soils in the municipality of Paragominas are deep, acidic and aluminum-rich dystrophic yellow latosols (Rodrigues *et al.*, 2003). It is hypothesized that this is a primary factor for the similarity between the points. This parameter also showed no relationship with local seasonality. Some studies have also shown this non-relationship between pH and seasonality in the Amazon, but related to groundwater (Nunes *et al.*, 2012; Meschede *et al.*, 2018).

The higher EC in the areas of temporary crops, P3 - Crop2, compared to the other areas (Figure 2), indicates a higher concentration of ionized substances dissolved in the water, being indicated as an indirect indicator of the presence of pollutants (Silva Filho *et al.* 2016; Leira *et al.* 2017). Although P2 is also represented by a temporary crop, its values were much lower compared to P3 (Figure 2). Greater values of electrical conductivity, even with a greater presence of riparian vegetation around (Table 2), demonstrate that there are other factors that also affect water quality, other than the simple existence of riparian forest protecting the spring. The highest conductivity values were in the dry period, as well as for almost all the sampled points for this parameter (Figure 2). This behavior is to be expected, due to the lower volume of water and consequently a lower dilution power. Consequently, to the values below the legal limit found for EC, similar patterns were interpreted for the ions analyzed in the study (Table and Figure 2), even though there was a statistical difference between the collection points (Table 3).

Table 3. Results of statistical tests between spring water quality parameters and environmental aspects. Anova parametric test is symbolized by a positive sign (+) while the non-parametric Kruskal Wallis test is symbolized by an asterisk (*).

	Land Use		Seasonality	
	F/χ^2	p - value	p - value	r
pH*	9.0707	0.059	0.115	-
Cond*	12.502	0.014	0.184	-
DO^+	11.2	< 0.001	0.479	-
Turb*	8.1994	0.085	< 0.001	0.4406
Temp*	17.639	0.001	0.880	-
TN*	22.967	< 0.001	0.982	-
SO_4^{2-}*	7.0161	0.135	0.012	0.3241
Na^+*	18.684	0.001	0.921	-
K^+*	4.3335	0.363	0.002	0.3968
Mg^{2+}*	1.99	0.738	0.679	-
Ca^{2+}*	16.312	0.003	0.104	-

In particular, sodium concentrations were higher in all areas with a history of land-use change compared to secondary forest (Table 2). Sediments and nutrients normally have a positive relationship with degraded areas. In agricultural land, excessive fertilizers and soil erosion can lead to an increase in ions in the water body (Mello *et al.*, 2018; Poudel, 2016; Uriarte *et al.*, 2011). Another factor that intensifies the presence of this ion is the non-implementation of conservation practices in the areas of use, leaving the soil regularly exposed and subject to erosion in rainfall events (Calijuri *et al.*, 2015).

DO values showed typical behavior for spring waters (Souza *et al.*, 2003; Belluta *et al.*, 2009; Ramos *et al.*, 2018), with those of Pasture point (P1) showing slightly greater values (Table and Figure 2). Possibly, this higher concentration is due to the longer atmospheric-water interaction time, as oxygen is more present from direct absorption from the atmosphere and intensification of turbulence along the flowing water body (Nuvolari *et al.*, 2003; Janzen and Schulz *et al*., 2006). Turbidity did not differ between the sample points (Table 2). However, it usually showed high concentration during the rainy season, due to the increase of suspended particles in this period (Panhota and Bianchini Jr., 2003), as shown in Figure 2. High turbidity values are related to land use change, evidencing the functional absence of riparian forest, and unprotection of soils, susceptible to erosion (Primavesi *et al.*, 2002; Donadio *et al.*, 2005; Marmontel and Rodrigues, 2015). Even though the areas presented different levels of degradation of the surrounding riparian vegetation (Table 1 - Riparian Vegetation Description), this qualitative information was not sufficient to explain any drastic increase in nutrient loading to the springs.

Although the surface temperature remains constant in each of the areas, there is a variation in spring surrounded by Pasture Area (P1) (Table and Figure 2). Temperature increases in water bodies located near pasture areas were also recorded by De Lima Sousa *et al.* (2021), when studying the influence of land use and land cover on water quality in water bodies in Pau

Amarelo micro basin, state of Pará, and by Macedo *et al.* (2013), when studying the warming of streams related to land use in the southeastern Amazon. The authors emphasize that the suppression of vegetation in areas bordering water bodies ends up increasing the incidence of sunlight and, consequently, increasing water temperature. Seasonal temperature variations are part of the normal climate scheme. On the banks of springs surrounded by forest, there is a tendency for lower air and water temperatures due to shading, which reduces incident radiation. Although the collection points have different characteristics of riparian forest, and therefore different influences of solar incidence and shading, there was no statistical variation in the surface temperatures of the waters studied. Marmontel and Rodrigues (2015) and Marmontel *et al.* (2018) also presented temperature results in springs with different land use characteristics and riparian forest content, which did not differ along seasonality.

Total nitrogen values showed variation among sample points, but no average was higher than the current legislation, even in different seasonal periods, which shows a potential integrity of the springs in relation to this important organic parameter in water quality (Buck *et al.*, 2004). Mainly because this parameter is sensitive to the denudation of the riparian forest and the use of nitrogen-based fertilizers. However, these anthropogenic actions are usually carried out downstream of the springs, which our data cannot capture. An important shortcoming of our qualitative analysis of the area of each sampling point is that we did not assess the intensity of activities carried out in each area surrounding the sampling points. Variables such as this could possibly have been better analyzed through this quantification.

Some variables showed no variation for both land-use change and seasonality. Interestingly, some studies have shown similar results for assessments in springs in regions with different land use types (Ramos *et al.*, 2018; Jacobs *et al.*, 2018). According to Jacobs *et al.* (2018), deep groundwater can mix with water from shallower soil layers and precipitation, obscuring the groundwater signal. These parameters that showed no relationship with land use were those linked to the presence of suspended solids and ions (Table 3).

4. CONCLUSION

Understanding water quality responses to the interaction between anthropogenic and natural factors remains an important challenge, particularly in highly altered areas such as Paragominas. The results obtained in the physical-chemical analyses of the water samples are under equilibrium conditions, and their characteristics are within a pattern that is compatible with the current legislation. Despite the regularity of most of the parameters analyzed, it was possible to find variations in water quality among spring sample points involved in areas with different histories of land use. The results also indicate that the seasonality of the region does not interfere in almost all water parameters.

In addition to all the observations throughout the study, it is possible to integrate the change in the use and occupation of the basin, already defined in the legislation (Brasil, 1997) as a water management and planning unit, determining the variations observed at the points sampled during the period studied. It is important that the analysis and observation be systemic and that there is a monitoring period within the variations of the hydrological cycle of the basin, with comparisons between periods of different seasonality, combined with the observation and assessment of changes in the landscape of the study area. Studies and diagnoses that can provide support to management in basin areas constitute an important tool to direct public policies for environmental and social quality improvements toward the population who live in and near these basins.

5. ACKNOWLEDGEMENTS

The authors thank the National Council for Scientific and Technological Development (MCTI/CNPQ/Universal Call 14/2014. Process No. 457193/2014).

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