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Physical-chemical evaluation of the water quality of springs in the Floresta Manaós environmental protection area

In this, we studied the physical-chemical parameters and socio-environmental conditions of water of two springs in the Floresta Manaós environmental protection area, located in Manaus, Brazil. The results of the analyses of the macroscopic environmental impacts show little or no interference due to anthropic actions in the first of the springs studied (S1), while, in the second spring (S2), the degree of preservation according to the studied parameters, was E (very bad). Physical-chemical parameters, such as electrical conductivity of water and pH showed unfavorable. The study of potentially toxic metals in the springs revealed that the iron in S2 is above the permitted limit, which may be the cause of the high conductivity values observed.

Keywords: Environmental Protection Area; Springs; Physical-Chemical Analysis; Water Quality Index.

Avaliação físico-química da qualidade da água de nascentes da área de proteção ambiental Floresta Manaós

Neste, estudamos os parâmetros físico-químicos e as condições socioambientais da água de duas nascentes da área de proteção ambiental Floresta Manaós, localizada em Manaus, Brasil. Os resultados das análises dos impactos ambientais macroscópicos mostram pouca ou nenhuma interferência devido às ações antrópicas na primeira das nascentes estudadas (S1), enquanto, na segunda nascente (S2), o grau de preservação de acordo com os parâmetros estudados, era E (muito ruim). Parâmetros físico-químicos, como condutividade elétrica da água e pH apresentaram-se desfavoráveis. O estudo dos metais potencialmente tóxicos nas nascentes revelou que o ferro no S2 está acima do limite permitido, o que pode ser a causa dos elevados valores de condutividade observados.

Palavras-chave: Área de Proteção Ambiental; Nascentes; Análises Físico-Químicas, Índice de Qualidade da Água.

Topic: **Química Agrícola e Ambiental**

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Liciane Assis Pinheiro
Universidade Federal do Amazonas, Brasil
http://lattes.cnpq.br/2601105692970178
l.a.pinheiro@gmail.com

Sâmia Dourado de Albuquerque
Universidade Federal do Amazonas, Brasil
http://lattes.cnpq.br/3614739713566180
samia.albuquerque@gmail.com

Maurício Ribeiro Baldan
Instituto Nacional de Pesquisas Espaciais, Brasil
http://lattes.cnpq.br/7595333636841849
mauricio.baldan@gmail.com

Lianet Aguilera Domínguez
Universidade Federal do Amazonas, Brasil
http://lattes.cnpq.br/9985637983794180
https://orcid.org/0000-0002-6836-1916
lianetaguilera@gmail.com

Neila Braga de Almeida
Universidade Federal do Amazonas, Brasil
http://lattes.cnpq.br/8772300241940971
https://orcid.org/0000-0002-3935-4936
neilabraga@ufam.edu.br

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INTRODUCTION

Global population growth, rapid urbanization and development activities have inflicted significant pressure on the supply of fresh water, thus leading to severe water shortages (MAURICE et al., 2019; CHEDADI et al., 2023; XU et al., 2019; WANG et al., 2023). Due to anthropogenic actions, the accumulation of potentially toxic metals (PTMs) and other pollutants in the aquatic environment has been growing annually and represents a risk to human health, and fauna and flora as a result of their bioaccumulative potential (MARTINS et al., 2022; PEREIRA et al., 2022). Therefore, it is important to carry out periodic analyses of the degree of contamination in ecosystems.

The springs are defined as environmental systems where the appearance of groundwater occurs naturally. This can be temporary or perennial and the surface hydrological flow is integrated into the drainage network, which culminates in the formation of a watercourse (HUSAIN et al., 2024). For the spring to be considered healthy, it must supply good quality water in an abundant and continuous manner and the flow variation should not be significant throughout the year (KIWANUKA et al., 2023). The springs are considered permanent protection areas (PPA), which are legally protected areas that contribute to the preservation of water resources, ecosystems, and biodiversity (BRASIL, 2012).

According to Brazilian Federal Law No. 12.651/12 (Forestry Code) (Brasil, 2012) [9], the areas around the springs, within a minimum radius of 50 meters, must be occupied by native vegetation and kept preserved. Establishing acceptable standards for bodies of water and classifying them in Brazil is the responsibility of the National Council for the Environment (CONAMA) via Resolution No. 357, of March 17, 2005, which considers that the deterioration of water quality must not affect the health or well-being of the population, as well as the aquatic ecological balance (BRASIL, 2005).

The Federal University of Amazonas (UFAM) has an area of approximately 6.7 square kilometers, which is located in the urban environment, and is classified as the third largest green urban fragment in the world and the largest urban fragment in the country. It is part of the environmental protection area (EPA) Floresta Manaós, which delimits a sustainable conservation unit in the east zone of Manaus and, according to the city’s cartographic base, possesses nineteen registered springs (SOUZA FILHO et al., 2019).

Springs are important for the fauna and flora of the environmental protection area; however, they have been facing neglect by institutions. The absence of protection around the springs can also facilitate the flow of people and animals, causing trampling and, consequently, changes in the flow of the springs. This is confirmed by the pollution of the streams inside the forest, which is produced by residential sewage from houses on the margins of these water bodies. In addition, in this region, there is the disposal of liquid waste that is produced by premises at UFAM. Furthermore, in the literature, there are no studies that characterize the quality of water of the springs in this protection area. Another relevant fact is that the springs located in this protection area are tributaries of two of the most expressive water courses in the urban area of Manaus, namely the Igarapé do Quarenta and the Igarapé do Mindu (SOUZA FILHO et al., 2019; CALVO et al., 2020).

Thus, the main purpose of this work was to survey the physical - chemical and socio-environmental conditions that characterize the region adjacent to the springs in the Floresta Manaós environmental protection area, as well as evaluate the quality of the water from these springs based on physical-chemical parameters and water quality indexes.

METHODOLOGY

Study area

The area chosen for the *in situ* collections was the environmental protection area (EPA) Floresta Manaós, with a focus on the forest on the campus of the Federal University of Amazonas (UFAM), as illustrated in Figure 1.

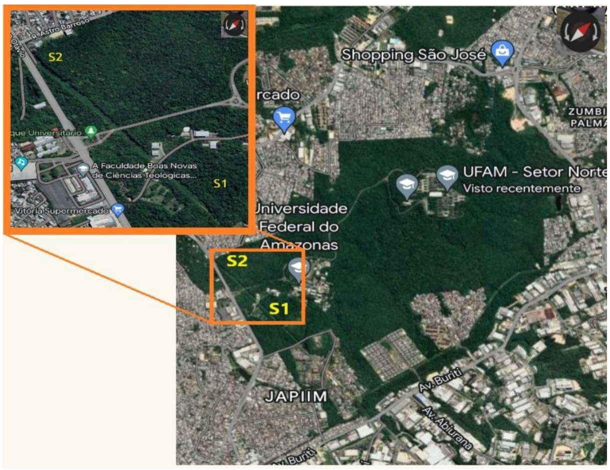

Figure 1: Area of the EPA Floresta Manaós where the collections were carried out. S1 located at geographic coordinates 59° 58' 40''W longitude and 03° 06' 11''S latitude and S2 located at coordinates 59° 59' 01''W longitude and 03° 05' 51''S latitude.

The chosen points were named S1 and S2. The S1 spring is in an area that is more difficult to access with geographic coordinates 59º58’40’’W longitude and 03°06’11’’S latitude. The S2 spring is located close to a residential area with busy avenues and is consequently less protected. Its geographic coordinates are 59°59’01’’W longitude and 03º05’51’’S latitude.

Collection of samples and determination of parameters *in situ*

Before collection, 1 L polyethylene flasks were soaked in 10% nitric acid (HNO_3) for 24 h, after which they were rinsed with deionized water. During sample collection, the values for the water quality indicators were obtained. The analyses in situ were performed in triplicate using a multiparameter probe (Akso, AK 88) and a turbidimeter (Akso, TU430). The results obtained were correlated to the conditions and standards established in the CONAMA Resolution No. 357 of 2005 (BRASIL, 2005).

Samples were also collected for *ex situ* analysis of total suspended solids (TSS) and determination of potentially toxic metals (PTMs). For this, the samples were stored in a cooler with ice to preserve their properties during transfer to the laboratory.

In order to diagnose water quality, in addition to taking microscopic parameters into account, macroscopic parameters were also used. For this, the Environmental Impact Index in Springs (EIIS) presented in Table 1 (CARVALHO et al., 2020) was used.

Table 1: Environmental Impact Index on Springs.

Macroscopic Parameters	**Attributes**		
	Weight 1	**Weight 2**	**Weight 3**
Watercolor	Dark	Clear	Transparent
Odor	Strong odor	Weak odor	No odor
Garbage nearby	Considerable	Little	No garbage
Floating materials	Considerable	Little	No floating material
Signs of fire	Considerable	Little	Absent
Sewage	Direct flow	Rain flow	Absent
Vegetation	High degradation	Low degradation	Preserved
Use by animals	Presence	Trace evidence	Absent
Anthropic use	Presence	Trace evidence	Absent
Protection	No protection	With protection/with human access	With protection/ without human access
Proximity to residences	Less than 50 m	Between 50 and 100 m	Over 100 m
Insertion area types	Absent	Private properties	Parks or protected areas

The springs had their degrees of preservation classified according to Table 2. These ranged from excellent to poor based on the score obtained in the previous table.

Table 2: Classification according to the degree of preservation.

Class	**Degree of preservation**	**Final score**
A	Excellent	33 - 36
B	Good	30 - 32
C	Reasonable	27 - 29
D	Bad	24 - 26
E	Very bad	0 - 23

Total Solids in Suspension (TSS)

TSS were determined by the gravimetric method based on the 24th edition of Standard Methods protocol No. 2540 D (APHA et al., 2023). For filtering the samples, three 44 mm 1.2 µm glass microfiber membranes were used, which were previously prepared by performing three successive applications of 100 mL of distilled water and vacuum filtration. Membranes were dried in an oven at 105 ± 2 ºC for 1 h, then cooled in a desiccator to room temperature and, finally, the mass of each glass microfiber membrane was measured on an analytical balance.

To filter the samples, the samples were first homogenized and then vacuum filtered in repetitions of three 100 mL aliquots. The material retained on the membrane was dried in an oven at 105 ± 2 ºC for 1 h. The membranes were cooled in the desiccator for approximately 30 min to reach room temperature and then the mass of each fiberglass membrane containing the solids was measured on the analytical balance. The cycle of drying, cooling, and weighing was repeated until a constant mass was obtained. The concentration of the TSS was determined using Equation 1.

$$C_{TSS}\ (mg * L^{-1}) = \frac{m_2 - m_1}{V} * 10^6 \qquad (1)$$

Where:
m_2 is the mass in grams (g) of the membrane with the sample after filtering and drying;
m_1 is the mass in grams (g) of the membrane without the sample;
V is the volume of the sample in milliliters (mL).

Determination of potentially toxic metals using an ICP-OES

For the determination of the PTMs was used an inductively coupled plasma atomic emission spectrometer (ICP-OES) (Thermo Scientific, iCAP-7600 DUO), using an ultrasonic nebulizer (CETAC, ASX 520), and an autosampler (CETAC, U5000AT+). The reading parameters for each element can be seen in Table 3.

Table 3: Reading parameters for determination of potentially toxic metals.

Reading parameters		
Elements	**Wavelength (nm)**	**Torch Position**
Al	396.152	Axial
Cd	228.802	Axial
Cu	324.754	Axial
Fe	259.940	Radial
Ni	231.604	Axial
Pb	220.353	Axial
Zn	206.200	Radial

RESULTS AND DISCUSSION

Macroscopic environmental impacts on springs

Based on the *in situ* visual analysis of the springs, an assessment was made of the degree of macroscopic environmental impacts in S1 and S2. Table 4 lists the EIIS parameters and the classification of the degree of preservation of the springs according to the data obtained.

Table 4: Quantification of the analysis of the macroscopic parameters of the springs and classification of the degree of preservation.

Macroscopic parameters	**Springs**	
	S1	**S2**
Watercolor	3	2
Odor	3	3
Garbage nearby	3	2
Floating materials	3	2
Signs of fire	3	2
Sewage	3	2
Vegetation	3	2
Used by animals	2	1
Anthropic use	3	1
Protection	3	2
Proximity to residences	3	1
Insertion area types	3	3
Total	**35**	**23**
Classification	**A**	**E**

From the results obtained, the degree of preservation of S1 and S2 can be verified. S1 with a final score of 35 was classified as A (excellent). This indicates interference from low-intensity anthropic actions, which is due to its location of difficult access within the forest of the UFAM campus. S2, on the other hand, had a high level of degradation and final score of 23 being classified as class E (very bad), which results from its proximity to residential areas and main avenues, and is an easily accessible spring.

Physical-chemical parameters

The data obtained from the analyses and processed according to the physical-chemical parameters are organized in Table 5.

The electrical conductivity (EC) of water indicates the conductive or insulating properties of water. Generally, pure water should be a good insulator of electrical current rather than a good conductor. The EC in water is mainly determined by the concentration of inorganic ions such as iron, cadmium, and zinc in aquifers. The results in Table 5 reveal that the EC had a relevant difference between S1 and S2, with the electrical conductivity of S2 being 4.5 times greater than the value of S1. This indicates a greater number of ions present in the water, which may be related to the low degree of preservation of S2. Electrical conductivity does not have a maximum value defined by CONAMA but the values obtained are comparable to those observed in waters from springs located in tropical forests (DAS et al., 2021; VIEIRA et al., 2024).

Solid matter in a suspended state determines the turbidity of groundwater or surface water. Turbidity assesses the clarity properties of water and is used to indicate the characteristics of waste discharge with respect to colloidal matter. Both S1 and S2 showed zero turbidity, with no particles in suspension. Dissolved oxygen (DO) values for both S1 and S2 were greater than 5.0 mg L^{-1}, and thus within the limits set by CONAMA.

Table 5: Physical-chemical parameters and comparison with CONAMA Resolution No. 357.

Parameters	S1	S2	CONAMA
EC (µS cm^{-1})	16.77 ± 0.06	73.5 ± 0.38	-
DO (mg L^{-1})	5.50 ± 0.10	6.70 ± 0.10	< 5.0
pH	4.88 ± 0.06	6.11 ± 0.02	6.0 - 9.0
Turbidity (UNT)	0.00	0.00	100.0
Temperature (°C)	26.23 ± 0.40	26.03 ± 0.55	≤ 40.0
TSS (mg L^{-1})	1.444 ± 0.193	0.556 ± 0.193	500.0

The acidic pH is a characteristic of rivers and streams in the Amazon region and is below the value permitted by CONAMA. Small aquatic environments located in forested areas are predominantly vulnerable to acidification due to the decomposition of the organic matter present in their beds (NISBET et al., 2014; CRÉMAZY *et al.* 2022). According to Table 5, for S2, the pH is less acidic than what is normally observed in the waters of the region (between 3.8 and 4.9), which may be indicative of environmental disturbance if we also take into account that this source was classified by the EIIS parameter as class E (very bad). The temperatures of the two springs were similar, which is consistent with the presence of vegetation in the surroundings.

As indicated by the CONAMA Resolution, the maximum amount of total suspended solids (TSS) is 500 mg L^{-1}. The TSS values of S1 and S2 were well below the maximum allowed, which indicates little suspended matter, whether of anthropic origin or not, which is consistent with the turbidity parameters obtained in both cases as well as the DO values.

Determination of potentially toxic metals

Table 6 shows the results of the concentration of metals present in the springs, as well as the limit of detection (LoD), limit of quantification (LoQ) and maximum value allowed by CONAMA Resolution No. 357 of 2005 (BRASIL, 2005). It is observed that the cadmium (Cd) and nickel (Ni) in S1 and S2 were below the LoQ of the equipment, as well as copper (Cu) in S1.

Table 6: Concentration of metals in springs and comparison with CONAMA Resolution No. 357.

Metal	S1 (mg L^{-1})	S2 (mg L^{-1})	LoD (mg L^{-1})	LoQ (mg L^{-1})	CONAMA (mg L^{-1})
Al	0.0831	0.0246	0.00023	0.0005	0.1000
Cd	< 0.0005	< 0.0005	0.00011	0.0005	0.0010
Cu	< 0.0005	0.0008	0.00039	0.0005	0.0090
Fe	0.1099	0.3786	0.00015	0.0005	0.3000
Ni	< 0.0005	< 0.0005	0.00031	0.0005	0.0250
Pb	0.0010	0.0007	0.00047	0.0005	0.0100
Zn	0.0008	0.0022	0.00017	0.0005	0.1800

From the values obtained for the concentrations of metals in S1 and S2, it is possible to infer that S1, due to its location of difficult access and high level of preservation, did not have any of the metals of interest above the maximum allowed. However, the iron (Fe) present in S2 was above the level permitted by CONAMA, which may be associated with inadequate discharge of domestic liquid waste and urban surface run-off. In turn, the high concentration of iron could be influencing the value of electrical conductivity in the waters of the S2 spring, as previously observed.

CONCLUSIONS

From the results obtained in the environmental impact study, it was demonstrated that spring S1 presents a good degree of preservation without significant environmental impacts. In the case of the spring S2, the degree of preservation was E (very bad), which indicates interference in the spring through improper human actions.

Minimizing the environmental impact on springs is crucial to guarantee the preservation of water resources and associated ecosystems, and actions are necessary for this purpose. Among them we can relate the establishment of continuous monitoring of springs, implementation of measures to control pollution such as regulation of activities and environmental education for the local community and strengthening of environmental legislation related to the protection of springs in order to guarantee their effective supervision to prevent damage and punish illegal activities that negatively impact these ecosystems. These conclusions highlight the importance of a comprehensive and collaborative approach to minimizing the environmental impact on springs, aiming to ensure the sustainability of these vital resources for life and the environment.

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