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Hydrochemical quality of springs and supply water in rural areas of the Mundaú River Watershed, Northeast Brazil

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ABSTRACT

Hydrochemical water quality research supports spring system monitoring, protection, and preservation. These springs, which are part of essential landscape processes, demand careful attention, due to their importance for the watershed and the services they provide to small rural areas. For this reason, this study was conducted to evaluate the hydrochemical water quality of springs correlated to the context of rural water supply in the Mundaú River Watershed, in Pernambuco and Alagoas, Northeast Brazil. Four samples of surface water from springs were analyzed in situ and a laboratory. The physicochemical and microbiological parameters were determined and compared to the environmental guidelines for freshwater protection. Part of the physicochemical and microbiological parameters evaluated in the four springs fell within the limits established by CONAMA No 357. Springs are the main source of water consumption for rural areas. Providing good quality water in these areas is challenging. The locations observed face several difficulties, from a lack of infrastructure and environmental awareness, and areas with difficult topography, to high implementation costs for water recycling systems. Anthropogenic interventions are the primary factors disrupting natural spring systems and compromising water quality.

Keywords: Subsurface outcrop; Physico-chemical analysis; Microbiological properties; Potability; Water consumption.

Qualidade hidroquímica da água de nascentes e abastecimento em espaços rurais, na Bacia Hidrográfica do Mundaú, Nordeste do Brasil

RESUMO

A investigação da qualidade hidroquímica das águas reforçam o gerenciamento, proteção e conservação dos sistemas de nascentes. Estas, que fazem parte de diversos processos essenciais na paisagem, merecem atenção, dado a importância que representam para a Bacia Hidrográfica e os serviços que fornece as pequenas comunidades rurais. Como tal, objetivou-se com esta pesquisa investigar a qualidade hidroquímica da água das nascentes e correlacionar com o contexto de abastecimento hídrico em espaços rurais, na Bacia Hidrográfica do Mundaú, Estados de Pernambuco e Alagoas, Nordeste do Brasil. Foram avaliadas, in situ e em laboratório, quatro amostras de água superficial de nascentes. Os parâmetros físico-químicos e microbiológicos foram determinados e comparados com as diretrizes ambientais de proteção das águas doces. Parte dos parâmetros físico-químicos e microbiológicos avaliados nas quatro nascentes estão dentro dos

limites permitido pelo CONAMA nº 357. As nascentes são os principais meios de acesso à água para o consumo das comunidades rurais. O abastecimento de água na condição de boa qualidade nestes espaços é um desafio. Diversas dificuldades são encontradas, desde a falta de infraestrutura e conscientização ambiental, locais topograficamente inacessíveis, a custos onerosos de implantação de sistemas de reuso de água. A intervenção antropogênica é o principal fator de desestruturação dos sistemas naturais de nascentes e comprometimento da qualidade da água.
Palavras-Chave: Afloramento subterrâneo; Determinação físico-química; Propriedades microbiológicas; Potabilidade; Consumo de água.

Introduction

Springs are essential hydro-environmental systems, and water quality serves as an indicator of anthropogenic pressures, reflecting the existing pressures and impacts across all points of the watershed's water systems. Although it provides only a partial view and requires the addition of other environmental data, the conditions of spring water and low-order streams can be useful in managing and protecting water resources (Maia et al., 2021).

The National Environmental Council (CONAMA) Resolution No. 357, published on March 17, 2005, stipulates optimal values for the physicochemical and microbiological properties of fresh, saline, and brackish waters. Consolidation No. 5, from September 28, 2017, based on Ordinance No. 1469/2000 (BRASIL, 2000) on controlling and monitoring drinking water quality and its potability standards, establishes microbiological standards for safe and adequate drinking water.

Water is a limited resource in many parts of the world (Nouayti et al., 2022) due to its highly vulnerable nature and the increasing number of potential pollution sources (Hmaidi et al., 2022). Despite extensive scientific research demonstrating the impacts of agriculture, industry, and urbanization on water, natural ecosystems are viewed merely as resources for exploitation. Despite several achievements based on the Brazilian Water Law, there is a need to enhance the protection and conservation of springs and vegetation ensuring both water quantity and quality.

Alitane et al. (2024) investigated 15 physicochemical parameters in the central region of the R'Dom watershed in northern Morocco and found that high levels of mineralization, combined with a high concentration of chemical elements in the water, significantly impacted water quality. They also noted that water quality improvements were strongly tied to reducing pollutant sources and establishing monitoring stations by relevant authorities.

The Mundaú River watershed covers a significant portion of the cities in eastern Pernambuco and Alagoas. Due to the frequency of flooding in the riverside communities and several contaminated water systems, a detailed analysis of the springs is required. This research aimed to investigate the hydrochemical water quality of springs correlated to the context of rural water supply in the Mundaú River Watershed, in Pernambuco and Alagoas, Northeast Brazil.

Material and methods

Physical-environmental background of the study area

The evaluated springs are located within the Mundaú river watershed in the Northeast of Brazil, covering the states of Pernambuco and Alagoas (Figure 1). The Mundaú river watershed primarily lies within Pernambuco, accounting for 54.90% of the total watershed area (2,447.50 km²). The remaining 45.10% (2,010.37 km²) falls within Alagoas, resulting in a total area of 4,457.87 km² and a perimeter of 382.68 km (Melo & Monteiro, 2022).

The watershed's drainage area covers 31 cities, inserted in a small part or throughout the entire region. It begins in a part of the territory of Pernambuco and flows into Alagoas, in the Mundaú-Manguaba Estuarine Lagoon Complex (CELMM) and is divided into six sub-watersheds: Upper, Middle, and Lower Sub-courses, Inhaúmas, Canhoto, and Satuba.

The Mundaú-Manguaba Estuarine Lagoon Complex (CELMM) is situated in Alagoas. It includes not only the state capital, Maceió, but also the cities of Marechal Deodoro, Pilar, Rio Largo, Satuba, Santa Luzia do Norte, and Coqueiro Seco. It is composed of two lagoons (Mundaú and Manguaba) and multiple channels, all linked to each other and the Atlantic Ocean (Luz et al., 2022). This tropical system of shallow lagoons, with a maximum depth of 3.5 m, is composed of three compartments: To the east, the Mundaú Lagoon, spans an area of 27 km², and primarily receives freshwater from the Mundaú river watershed; in the western portion, the Manguaba Lagoon, covers an expanse of 42 km² and receives an average annual discharge of 28 m³/s of freshwater from the Paraíba do Meio and Sumaúma river watersheds, and lastly, the system of narrow channels (12 km²) connects the lagoons to the Atlantic Ocean through a single tidal inlet, 250 m wide (Pinheiro et al., 2021).

This complex is comprised of one of the most important estuarine systems in Brazil, and it is currently experiencing accelerated environmental degradation.

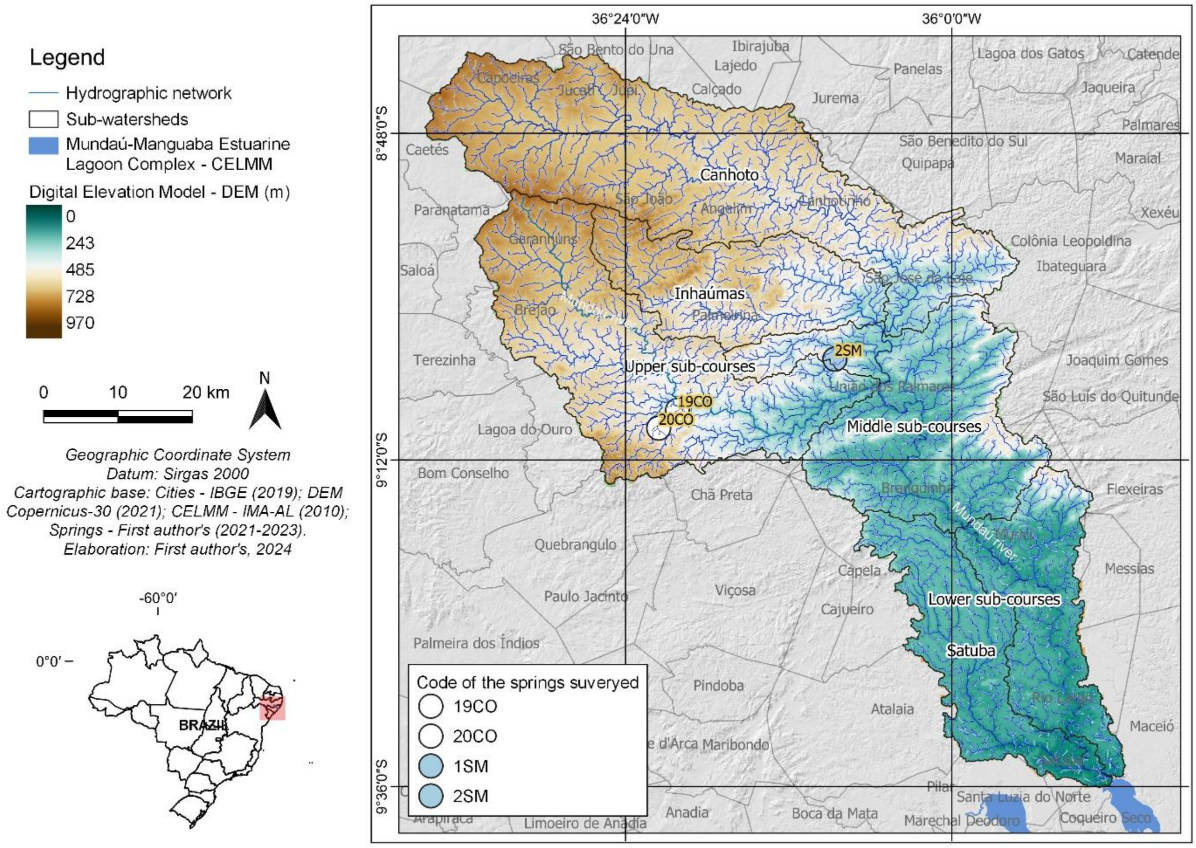


Figure 1- Springs analyzed in the Mundaú river watershed, Northeast Brazil, in the Upper and Middle Sub-courses.

In addition, the Mundaú Watershed is set within a regional background of the Borborema Plateau, a large portion of lithology composed of granitic rocks, gneisses, and granites, of the Crystallization Modeling, in charge of water drainage in Pernambuco, into the Atlantic Ocean in the eastern part of Alagoas (Corrêa et al., 2010; Jacomine et al., 1975). The climate of the area in question is Tropical Rainy with Dry Summers (As'), according to the Köppen classification (Köppen & Geiger, 1928).

This region's native vegetation consists of the Semi-evergreen Forest: a dense formation measuring between 20 m and 30 m, and the Subcaducifolia Tropical Forest, ranging around 20 m, and experiencing a noticeable amount of leaf loss during the dry season (Jacomine et al., 1975). The predominant soil classes are Red-Yellow Argisols and Yellow Argisols (Embrapa, 2018).

Description of the research

The methodological procedures were divided into stages, in order to optimize the analysis of the results obtained (Figure 2).

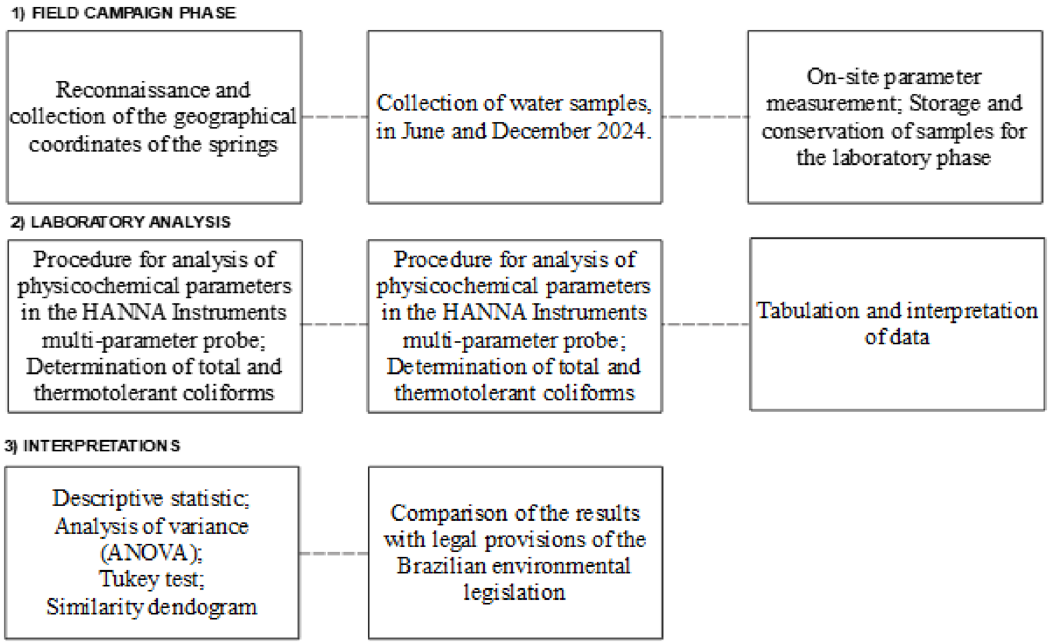


Figure 2- Methodological flowchart with the research stages.

Field identification and mapping of springs in the Watershed

The springs were identified, mapped, and photographed within each exfiltration environment. Every spring was labeled by a number and letter, according to the city where they were located, for better spatialization and discussion of results. For the Upper and Middle courses of the Mundaú river, four springs were surveyed (19CO, 20CO, 1SM, and 2SM) in two field surveys held in June and December 2022. Each spring's geographical coordinates were obtained by using a Garmin 64x GPS, following a plane coordinate system: Sirgas 2000 - UTM zone 24s.

The cartographic base of the Mundaú river watershed was developed using the Copernicus Digital Elevation Model with a 30-meter resolution, in order to compile the geo-referencing coordinates of each spring. They were organized into a .csv worksheet and then imported into the QGIS 3.16.2 GIS software (https://qgis.org/pt_BR/site/). The plane coordinate systems were converted to the geographic coordinate system: Sirgas 2000, EPSG code: 4674. Subsequently, the cartographic database was generated.

Analysis of physicochemical and biological water quality parameters

The field surveys took place in June 2022 (wet season) and December 2022 (dry season). Water samples were collected from springs 19CO, 20CO, 1SM, and 2SM. Analyses were performed on these samples in two laboratories: private and research partners. Field measurements were also taken. These samples were collected in 1 L PET bottles and 500 mL autoclavable bottles. After fully sterilizing both bottles and hands, the samples were gathered from the water sheet's surface and then stored in a cooler with ice for temperature control and biological preservation.

Physicochemical variables, including potential hydrogen (pH), water temperature (°C), electrical conductivity (EC), and Total Dissolved Solids (TDS), were measured in situ using a multiparameter probe (Model HI 9829, HANNA Instruments). Additionally, chemical parameters such as Nitrite (NO2-), Nitrate (NO3-), Ammonia (NH3 N), Phosphorus (P), Phosphate (PO_4^{3}-). were also measured. Phytoplankton biomass analysis, based on Chlorophyll a and Pheophytin a determinations, was conducted in the laboratory using a spectrophotometer (Model HI83399, HANNA Instruments), and UV spectrophotometry, (wavelengths of 110 to 1300 nm – Kasvi and Merck®) (Baird et al., 2017).

For the previously listed parameters conducted at the partner laboratory, A 10 mL sample of the springs' water was pipetted into a lidded cuvette. After the white reading was done, the corresponding reagent was added for estimation as required by the manual. The cuvette filled with the water + regent sample was shaken to ensure homogeneity. Finally, it was reinserted into the equipment, and the measurement time for each variable was awaited before recording the final readings.

The Aquateste was used as the culture medium for microbiological detectability in water samples, calculate the Most Probable Number (MPN/100mL) of total coliforms and thermotolerant coliforms (Escherichia coli) (Baird et al., 2017), and detects total coliforms through the enzyme β-galactosidase, which is involved in the fermentative metabolism of lactose.

100 mL of water samples were used in each Becker containing the water sample and culture medium. The 100 mL mixture was then homogenized on a shaker and divided into 20 mL aliquots in 5 sterile pre-labeled test tubes that were quickly covered with aluminum foil and incubated at 35°C in an oven for 24 hours. After incubation, the samples were checked for an intense yellow color and placed into an ultraviolet dark chamber for analysis.

In Brazil, the classification and environmental guidelines for surface freshwaters are regulated by the National Environmental Council (CONAMA) Resolution No. 357/2005. According to this resolution, water quality conditions are divided into five classes in accordance with their primary use: special, Classes 1, 2, 3, and 4 (Table 4). Each class imposes greater or lesser requirements concerning protection and quantity of parameters.

The parameter analyses were based on Class 1 water potability standards defined by CONAMA Resolution No. 357 of March 17, 2005 (Conama, 2005), Specifically, Section II - Freshwaters of this resolution establishes and provides subsidies for the limits for each water parameter.

Statistical analysis

Descriptive statistics, Analysis of variance (ANOVA) and Tukey's test were applied to the data, as this test shows the differences and similarities in the results between experimental variables. The physicochemical parameters and springs were compared in terms of correlation strength using a similarity dendrogram. All analyses were completed in Excel and Past 4.4.

Results and Discussions

Physicochemical properties of water quality

Four spring water samples were tested for physicochemical parameters and analyzed during two distinct periods: the wet season (June 2022) and the dry season (December 2022), to measure temporal variability. They were graphically expressed and interpreted in compliance with CONAMA Resolution No. 357/2005, instituted by Brazilian Federal Law No. 6.938/1981. Figures 3 to 7 present the results of the parameters analyzed: pH, Temperature, Electrical Conductivity, Total Dissolved Solids, Phaeophytin A, Chlorophyll A, Nitrate, Nitrite, Ammonia, Total Phosphorus and Phosphate.

The pH values of springs 19CO, 20CO, 1SM, and 2SM (Figure 3A) indicate slightly acidic to neutral to slightly acidic water, ranging from 5.9 to 6.6. Which means being within acceptable ranges for balanced aquatic life. Saturday et al. (2021) mention that a pH below 6.5 slows the growth of some aquatic species, while a pH > 6.5 affects the ability of certain organisms to maintain their salt balance and can cause a disruption in their reproduction.

A higher pH value was observed at spring 20CO, showing values of 6.6 and 6.5 in the wet and dry seasons (Figure 3A), while the lowest values were recorded at spring 2SM, with a pH of 5.9 over the two periods under analysis. Under the terms of CONAMA Resolution 357/2005 and Brazil's drinking water standards, the acceptable pH for Class 1 freshwaters must be between 6.0 and 9.5. Brito et al. (2024) recorded slightly acidic pH values, averaging 5.5.

Water temperature measurements ranged from 23.7 °C to 27.4 °C (Figure 3B). The highest temperatures recorded in all springs were observed in dry seasons, reaching 27.0 °C (19CO), 27.4 °C (20CO), 25.9 °C (1SM), and 26.8 °C (2SM) (Figure 3B). In contrast, the lowest temperatures, measured in June 2022, were 26.0 °C (19CO), 26.1 °C (20CO), 23.7 °C (1SM), and 24.2 °C (2SM) (Figure 3B). These results are consistent with the region's climate variability.

Applying the Tukey test, the results revealed no statistical difference between the samples ($p > 0.05$), except for nitrate (Figure 6A).

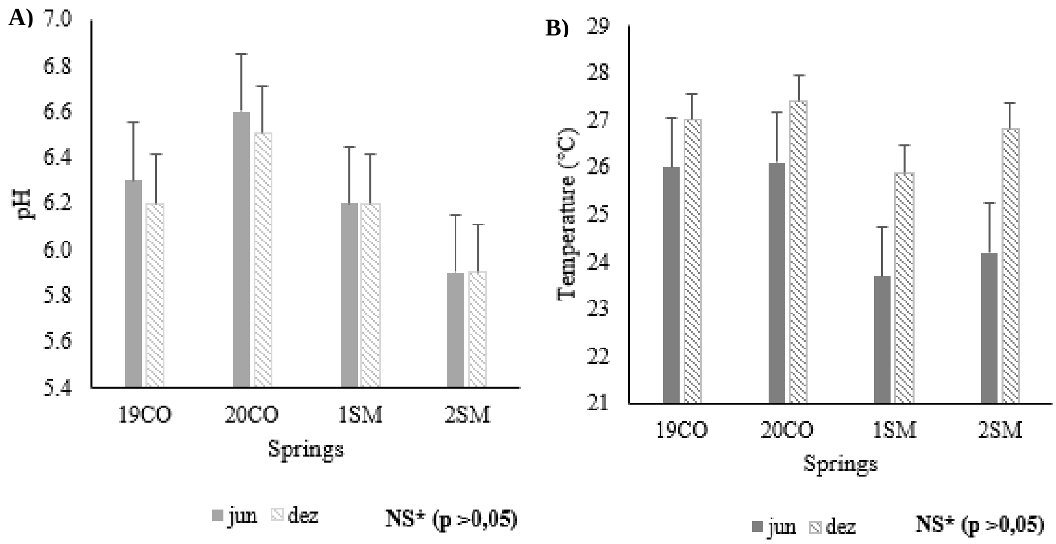


Figure 3- pH values (A) and temperature (B) in the 19CO, 20CO, 1SM and 2SM springs under analysis. *NS indicates no statistical difference using the Tukey test.

The values for electrical conductivity and total dissolved solids exhibited a similar pattern, indicating a direct correlation between the two parameters.

For the analyzed periods, the highest values were recorded during the wet season, in the following order: 210 µS/cm (19CO), 400 µS/cm (20CO), 110 µS/cm (1SM), and 110 µS/cm (2SM) (Figure 4A), highlighting the 20CO spring, where the wet and dry seasons reached values of 400 and 390 µS/cm, respectively.

The current Brazilian legislation does not establish an upper limit for this parameter. Although variations in water conductivity may not cause any immediate problems for humans, they are an indicator of water contamination through industrial effluent and even siltation of margins. CONAMA Resolution 357/2005, Ordinance 2914/2011 and Ordinance 888/2021 do not stipulate a maximum permissible limit for this parameter.

Consequently, the total dissolved solids in the samples were estimated to range between 40 and 190 mg/L (Figure 4B). The highest values occurred in the wet and dry seasons at the 20CO spring, reaching 190 mg/L, respectively. According to Fikadu (2022), the high TDS values are attributed to waste accumulation. Additionally, slope processes are linked to these elevated TDS levels, which are intensified by the lack of natural vegetation cover in the Correntes area.

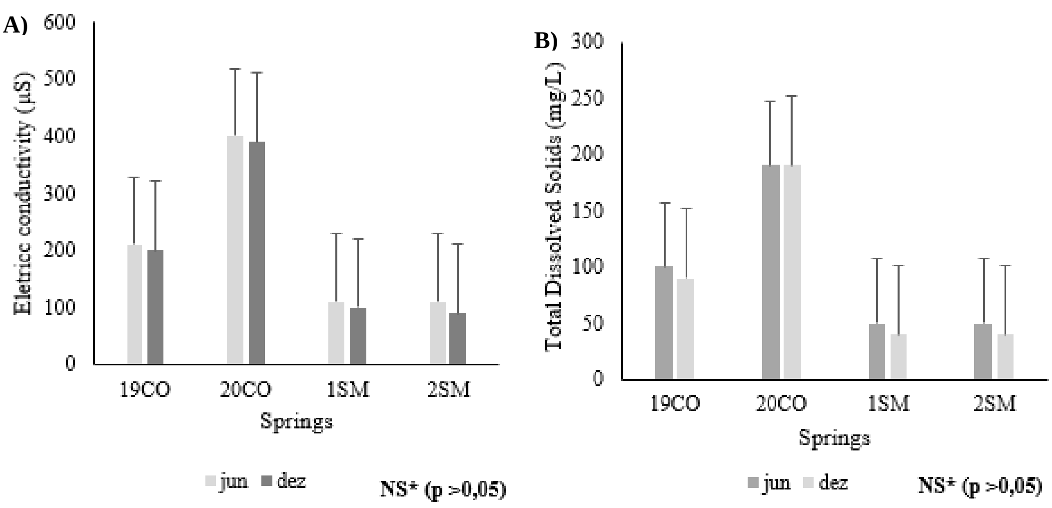


Figure 4- Electrical conductivity values (A) and total dissolved solids (B), 19CO, 20CO, 1SM and 2SM. *NS indicates no statistical difference using the Tukey test.

Pheophytin a and chlorophyll a were detected in concentrations in compliance with the Class 1 CONAMA resolution. Pheophytin reached maximum levels of 3.96 and 1.31 µg/L at 2SM and 1SM springs in December (Figure 5A), indicating that high levels could jeopardize the water's environmental quality. Concurrently, chlorophyll a values were also elevated for the same period and springs, reaching 6.33 and 7.48 µg/L (Figure 5B). CONAMA 357/2005 establishes a limit of 30 µg/L for Class 2 fresh waters. In their study, Fernandes et al. (2023) reported that the presence of chlorophyll is associated to the depth of these wells, as it is a typical aspect of surface waters, but the primary warning refers to the presence of cyanobacteria in the environment, producers of toxins that could lead to severe health issues if humans consume the water.

A comparison of water samples collected during the wet and dry seasons revealed contrasting patterns in Phe-a and Chl-a levels between springs.

In springs 19CO and 20CO, these pigments were higher in the wet season and lower in the dry season (Figure 5A and 5B). Conversely, springs 1SM and 2SM exhibited lower Phe-a and Chl-a concentrations in the wet season compared to the dry season (Figure 5A and 5B). This can be attributed to the differences found in the fencing of the springs: in Correntes, the springs are sealed with soil-cement, while those in Santana are open. Furthermore, the timing of the field surveys may have influenced the results. The samples were collected after intense rain events, followed by low flow rates and sunny weather. These conditions can affect the hydrochemical dynamics of the water.

The Brazilian Ministry of Health's Ordinance No. 578 mandates monthly monitoring of cyanobacteria in springs, with a maximum permissible cell density of 10,000 cells per mL. High cyanobacteria levels require weekly monitoring due to the potential presence of cyanotoxins. These toxins pose a risk to the local population and render the water unsuitable for public water supply, recreation, or irrigation. Additionally, bioaccumulation of cyanotoxins in fish and bivalve mollusks poses a further health concern (BRASIL, 2006).

There are additional comments regarding flow seasonality. Physical changes can occur between seasons, with temperature and variations in water movement either inhibiting or enabling algal growth. Gomes et al. (2020) indicate that the hottest and driest conditions favor chlorophyll production in low water flow environments, so the water movement may be a limiting factor for algae, justifying any observed differences seen in the wet and dry seasons.

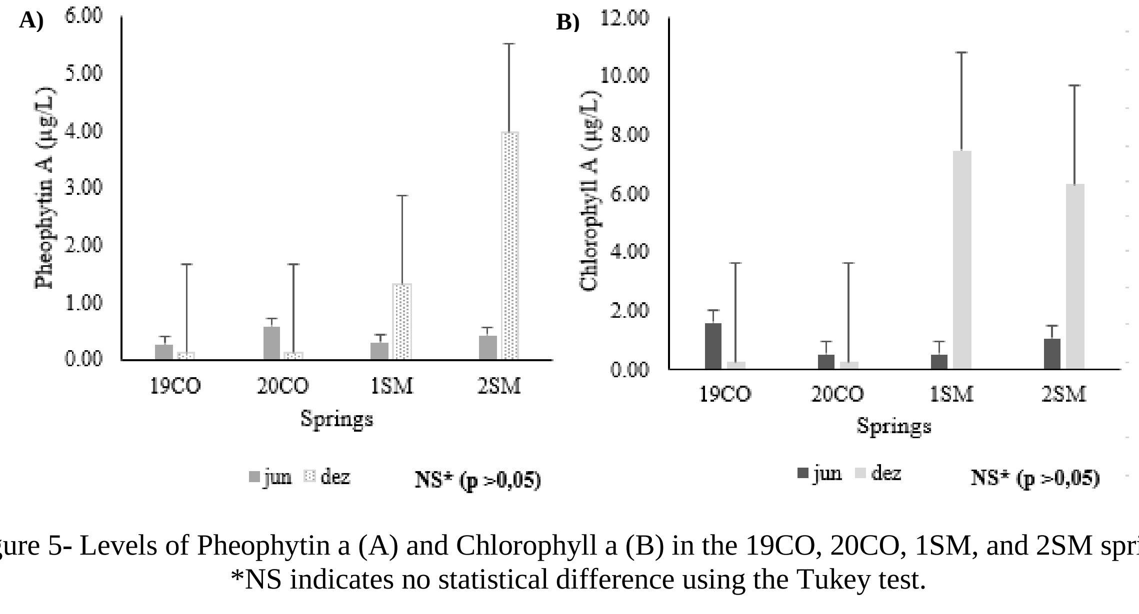


Figure 5- Levels of Pheophytin a (A) and Chlorophyll a (B) in the 19CO, 20CO, 1SM, and 2SM springs. *NS indicates no statistical difference using the Tukey test.

The nitrite and nitrate determinations demonstrate the region's climatic variability. Nitrite values were obtained using a photometer and a spectrophotometer. The results differed due to the difference in wavelength reached by each instrument. The values obtained comply with CONAMA Class 1 requirements, ≤ 1.00 mg/L.

Using an optical photometer sensor, the nitrite values ranged from 0.001 to 0.008 mg/L in springs 19CO and 20CO, and from 0 to 0.002 mg/L in springs 1SM and 2SM (Figure 6B). In contrast, when the spectrophotometer sensor was utilized, nitrite concentrations were 0.70 and 0.496 mg/L in springs 19CO and 20CO, and 0.019 to 0.318 mg/L in springs 1SM and 2SM (Figure 6C).

The presence of nitrogen in water bodies is a consequence of the discharging of effluents or products used in agriculture. It manifests predominantly in the forms of organic nitrogen (40%) and ammonia (60%). Ammonification, the process of organic matter decomposition mediated by heterotrophic organisms, predominantly occurs in the sediment of aquatic environments.

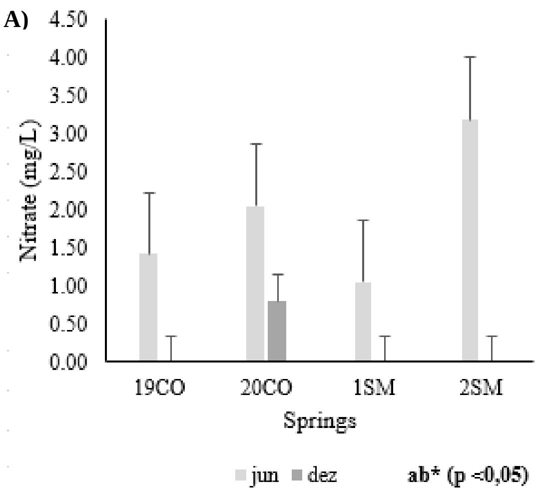
In aquatic environments, this compound can originate from biological degradation of organic matter. Elevated ammonia concentrations in natural waters serve as a clear indicator of contamination from raw wastewater, industrial effluents, or fertilizer flows (Silva et al., 2021).

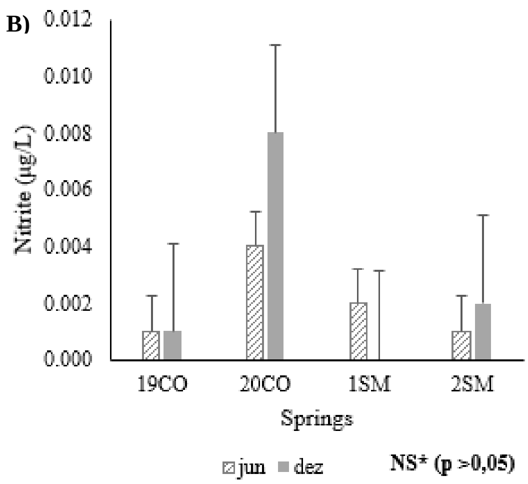
An analysis of the wet and dry seasons showed that nitrate determinations were higher in the dry season (Figure 6A). Kiwanuka et al. (2023) identified differences in the results during the dry and wet seasons. In compliance with the advisory limits of Brazilian legislation, which stipulate values below ≤ 10.00 mg/L, the measured nitrate levels also fell within the prescribed range.

In springs 19CO and 20CO, the minimum and maximum values ranged from < 0.0001 to 2.04 mg/L (Figure 6A) and in Santana do Mundaú springs, they ranged from < 0.0001 to 3.18 mg/L (Figure 6A), respectively.

Several human health disorders may be linked to high nitrite levels. Usually, in natural environments, these levels are low, but they increase with anthropogenic activities, such as agriculture, widespread fertilizer application, and the discharge of domestic effluents and septic tanks (Liu et al., 2021). These specific conditions are clearly observed in spring environments.

Statistical analysis of the nitrate values (Figure 6A) revealed a significant difference among the factors, indicating that the nitrate concentrations across all springs exhibited distinct patterns "ab" ($p < 0.05$).





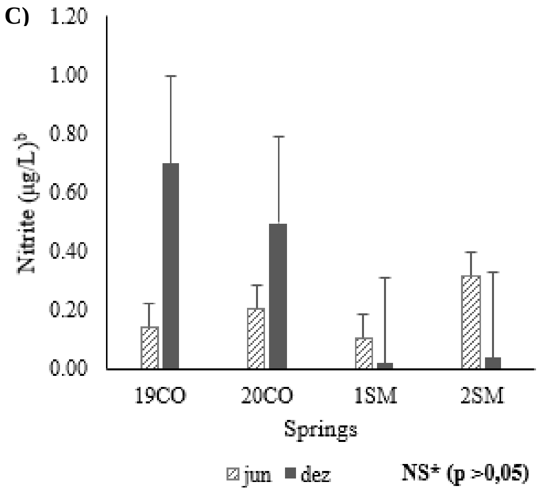


Figure 6- Nitrate (A), nitrite by photometer (B), and nitrite by spectrophotometer (C) in springs 19CO, 20CO, 1SM, and 2SM. *ab indicates statistical difference using the Tukey test; NS indicates no difference. [b]Nitrite determined using the MERCK 1.09713 method.

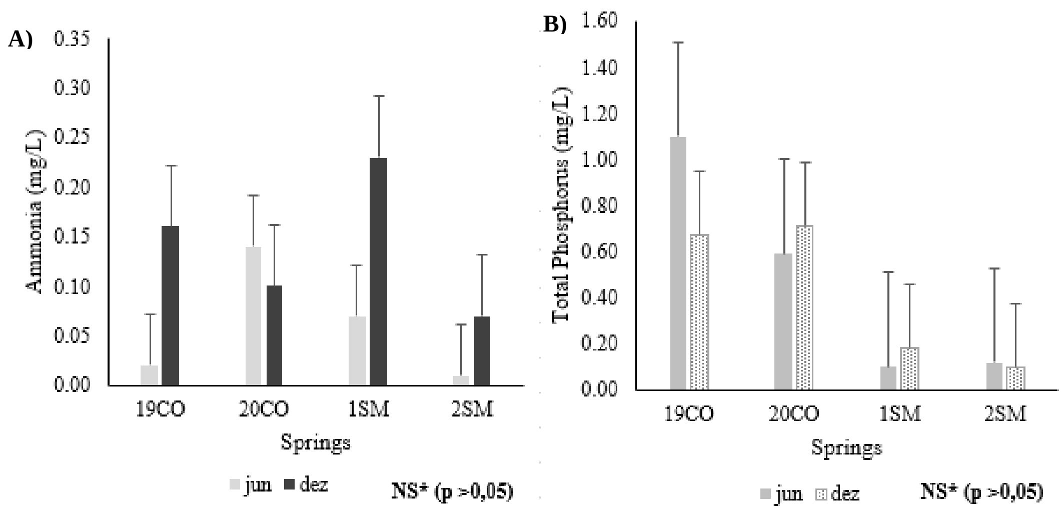
Ammonia concentrations fell within the limits allowed by CONAMA resolution, and the total phosphorus levels found in the study exceeded the Class 1 limits: ≤ 0.020 mg/L. Phosphate values, although not regulated by the aforementioned law, are elevated compared to World Health Organization (WHO) guidelines, which stipulate maximum limits of <0.10 mg/L. The minimum and maximum ammonia values ranged from 0.02 to 0.16 mg/L in springs 19CO and 20CO and from 0.01 to 0.23 mg/L in springs 1SM and 2SM (Figure 7A).

Regarding total phosphorus, the levels ranged from 0.59 to 1.10 mg/L. In the Correntes springs, there were between 0.10 and 0.18 mg/L (Figure 7B). The surplus of nutrients, such as phosphorus and nitrogen, promotes massive algal blooms, leading to eutrophication and its adverse effects on aquatic life (Saturday et al., 2021).

Phosphorus concentrations can be related to natural processes such as leaching, rock dissolution, organic matter decomposition, anthropogenic processes such as the use of pesticides, fertilizers, and detergents, as well as the direct discharge of wastewater into water bodies.

Phosphate levels ranged from 1.81 to 3.38 mg/L in springs 19CO and 20CO and from 0.30 to 0.57 mg/L in springs 1SM and 2SM (Figure 7C).

Natural and artificial land use affects water quality in several ways in different watershed scales, so studying the limnological characteristics of water is important to understand the impacts of land use (Ma et al., 2024).



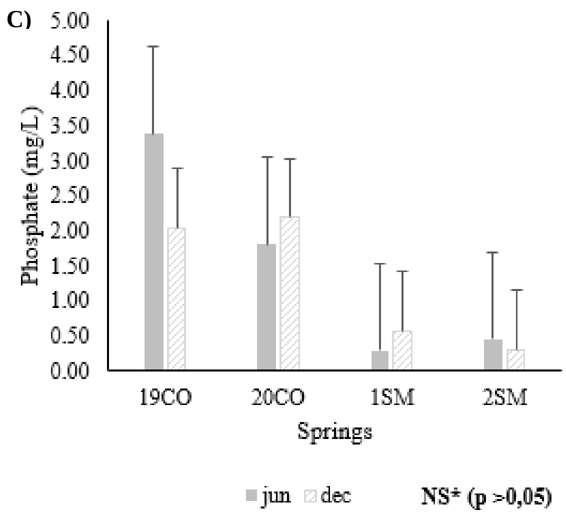
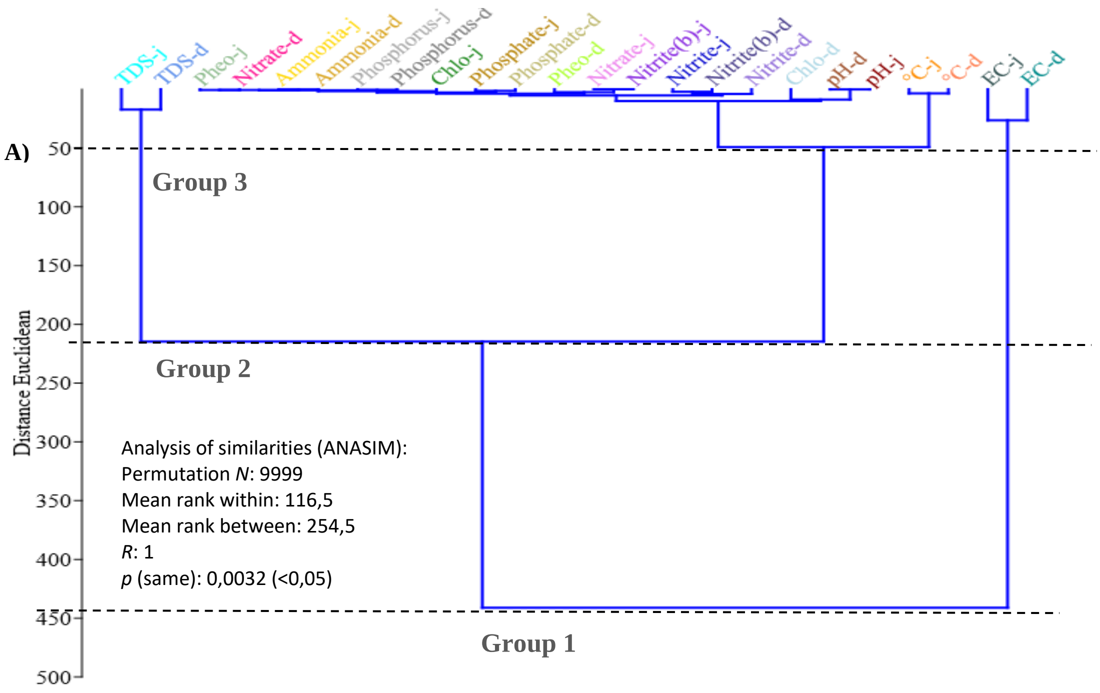


Figure 7- Determinations of ammonia (A), total phosphorus (B), and phosphate (C) in springs 19CO, 20CO, 1SM, and 2SM. *NS indicates no statistical difference using the Tukey test.

Correlation between variables

Similarities between the physico-chemical parameters in the wet and dry seasons (Figure 8A) indicated the presence of two major groups. Subsequently, five sub-groups emerged: 1) Correlation coefficient of electrical conductivity measurements between the two seasons (EC-j and EC-d); 2) temperatures (°C-j and °C-d); 3) pH-j, pH-d and chlorophyll-d; 4) nitrite-d, nitrite(b)-d, nitrite-j, nitrate-j, pheophytin (Pheo-j), phosphate-d, phosphate-j, chlorophyll (Chlo-j), phosphorus-d and phosphorus-j, ammonia-d, ammonia-j, nitrate-d, pheophytin (Pheo-j) and 5) total dissolved solids (TDS-j and TDS-d) (Figure 8A). The p -value in the similarity analysis was less than 0.05, indicating statistically significant differences between the compared samples.

Analysis of similarity among springs (Figure 8B) revealed three distinct and correlated groups: group 1 (20CO), group 2 (19CO), and group 3 (2SM and 1SM) (Figure 8B).



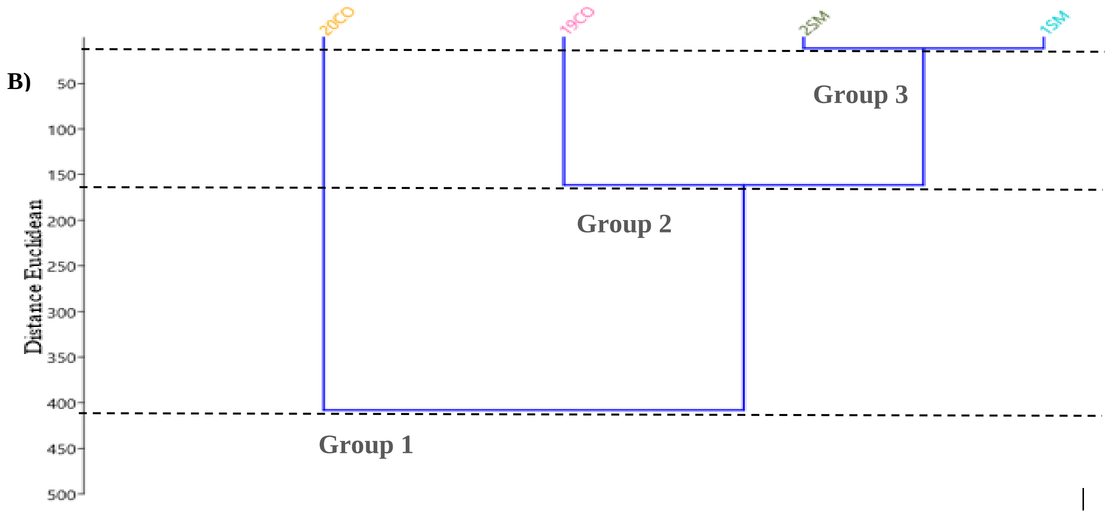


Figure 8- Dendogram of similarities between the physicochemical parameters in wet and dry periods (A) and between the springs (B). j refers to June, and d to December.

Microbiological properties of water quality

Since springs are considered Permanent Preservation Areas (APPs) under Law 12.651/2012, in accordance with CONAMA, they fall under the category of special class freshwater, which are those with more demanding uses. According to this resolution, they are designated to preserve aquatic communities and human supply once the water has been properly disinfected. A limitation is perceived when examining the specifications of the physicochemical and microbiological parameters in the special use class since there are no water quality standard determinations, leading to the precariousness of springs.

Total coliforms were detected as positive in the evaluated samples, in June 2022 (wet season) and December 2022 (dry season) (Table 1). The presence of total coliforms shows poor hygienic quality of spring waters. High-quality mineral waters are classified as excellent for their concentration of mineral salts and/or the characteristics of the spring. However, the hydrogeological context of the region will influence this according to the Mineral Water Code (BRASIL, 2021).

The presence of thermotolerant coliforms indicated pathogen growth in 5 test tubes > 8.0 NMP/100mL in the samples from springs 1SM and 2SM in December 2022 (Table 1), revealing microbiological contamination. Both total coliforms and Escherichia Coli are bacteria that inhabit the large intestines of warm-bloode d animals. The detection of *Escherichia coli* points to the presence of pathogens, and disease-causing organisms, such as bacteria, protozoa, and viruses (Kiwanuka et al., 2023).

Their presence points to water pollution, making them valuable indicators of water unsuitable for human consumption. The Brazilian Ministry of Health's Ordinance No. 2.914/2011 establishes the absence of total coliforms and *Escherichia coli* in 100 mL samples of drinking water. The detection of these bacteria in water serves as a crucial indicator, especially concerning wastewater management.

More regulations, such as Ordinance No. 888/2021, establish and reinforce the importance of controlling and monitoring the quality of water for human consumption and its potability standards, demanding the absence of total coliforms and thermotolerant coliforms (*Escherichia coli*), a common non-applicable reality (BRASIL, 2021).

These springs face a major risk factor due to constant fecal contamination. Their microbiological quality is affected by their proximity to residential areas, lack of sanitation infrastructure, such as septic tanks, wastewater disposal, organic waste in the surroundings of the springs and herding animals. The hazardous situation of these springs results from poor environmental preservation and, most of all, due to human interference in removing native vegetation, widespread agriculture, the alteration of the springs' natural state, solid waste, and pesticide contamination. This situation is especially alarming for the local population's health, as they consume the contaminated spring water without any treatment.

It is crucial to emphasize that water quality assessments should be conducted in an integrated manner, encompassing a range of physical, chemical, and biological data (BRASIL, 2006). The social context must be also considered, as it is essential for understanding the landscape's dynamics.

Table 1- Total Coliforms and Thermotolerant Coliforms in Surface Waters from Four Springs in Correntes and Santana do Mundaú.

Parameters	Junho 22 (Wet season)				Dezembro 22 (Dry season)			
	19CO	20CO	1SM	2SM	19CO	20CO	1SM	2SM
Total Coliforms (NMP/100mL)	Positive							
Thermotolerant Coliforms - *Escherichia Coli* (NMP/100mL)	0 (<0,1)	0 (<0,1)	0 (<0,1)	0(<0,1)	0 (<0,1)	0 (<0,1)	5 (>8,0)	5 (>8,0)

Scenario and challenges in rural water supply

Providing a good quality water supply in rural areas is challenging. The locations observed face several difficulties, from a lack of infrastructure, and areas with difficult topography, to high implementation costs. Water supply for rural areas is primarily provided by springs, wells and nearby rivers, the main source of water consumption for underprivileged communities. The situation concerning basic sanitation is critical. In a significant portion of homes, there is no wastewater treatment or septic tanks, which results in the direct discharge of wastewater into springs and rivers.

In its general assembly resolution 64/A/RES/64/292 of 2010, the United Nations (UN) has recognized that: "Access to potable water and basic sanitation is an essential, fundamental and universal human right, indispensable for a life of dignity". This vital access has been neglected for a long time. Without any guarantees of basic services, rural populations live without water and wastewater treatment, further burdened by the resulting social inequalities.

To minimize the difficulties of accessing high-quality water, local communities adopt various interventionist practices, such as surrounding the springs with brickwork (Figure 9A) or utilizing other techniques like soil-cement. These practices, however, limit and do not contemplate Permanent Protection Areas (PPAs), may lead to the depletion of spring water, and depending on the method employed, introduce additional contamination risks.

According to global statistics, 30.1% of the planet's fresh water is groundwater, under intense pressure from anthropogenic contamination due to the impact of climate change, urbanization, industrialization and agriculture (Kiwanuka et al., 2023; Twinomucunguzi et al., 2021). So guaranteeing both water quantity and quality in springs requires preserving and conserving the last fragments of native vegetation present in these areas.

In spring environments, only small herbaceous plants and shrubs remain, reaching heights of just a few centimeters. These do not provide adequate protection for the springs, leaving the water vulnerable to eutrophication by algae and cyanobacteria (Figure 9B). Due to contamination caused by the application of pesticides, chemical deforestation of vegetation, and solid waste, the spring's hydroenvironmental system becomes unbalanced (Figure 9C). Given the concerning and ample environmental scenario, groundwater and surface water quality needs to be prognosticated, as well as identify the major obstacles to spring protection. This will enable integrative solutions to be considered and applied, such as social technologies and environmental education.

Figure 9- Intervention performed at the springs (A), biological eutrophication of the water (B), garbage disposal near spring 1SM (C). Source: Author's elaboration (2023).

Conclusions

All analyzed physicochemical parameters (pH, temperature, electrical conductivity, total dissolved solids, pheophytin a, chlorophyll a, nitrite, nitrate and ammonia) in the four springs fell within the limits established by the advisory body;

The levels of total phosphorus and phosphate are above the permitted values in both the rainy and dry seasons;

The presence of total and thermotolerant coliforms in the samples points to potential pathogenic bacteria, due to the poor hygiene conditions at the springs. These conditions could be caused by the disposal of solid organic and inorganic waste, human and animal waste, and household water;

Springs are the primary source of water for rural areas. Providing good quality water in these areas is challenging. The locations observed face several difficulties, from a lack of infrastructure and environmental awareness, and areas with difficult topography, to high implementation costs for water recycling systems;

Anthropogenic interventions are the primary factors disrupting natural spring systems and compromising water quality.

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