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SEASONAL VARIATIONS AND WATER QUALITY IN AMAZONIA: A COMPARATIVE STUDY OF PUBLIC SUPPLY SYSTEMS IN ORIXIMINÁ, PARÁ, BRAZIL

Variações Sazonais e Qualidade da Água na Amazônia: Um Estudo Comparativo dos Sistemas Públicos de Abastecimento em Oriximiná, Pará, Brasil

Variaciones estacionales y calidad del agua en la Amazonia: un estudio comparativo de los sistemas de abastecimiento público en Oriximiná, Pará, Brasil

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ABSTRACT

Introduction: Assessing water quality for human consumption is essential to ensure its suitability and mitigate health risks by preventing waterborne diseases. **Objective**: To evaluate the physicochemical and microbiological parameters of water supplied by two public systems in Oriximiná, Pará, Brazil, and to identify seasonal variations in these parameters during drought and flood periods. **Methodology:** The study compared two water supply systems: Companhia de Saneamento do Pará (Cosanpa) and Residencial Tia Ana. Water samples were collected monthly from January to December 2021 and analyzed for pH, apparent color, temperature, turbidity, chlorine, and coliforms following standardized procedures. Statistical analysis utilized Student's t-test and paired t-test with a significance level of 0.05. **Results:** The average temperature did not differ significantly between Cosanpa (22.5°C) and Residencial Tia Ana (22.3°C). Turbidity was higher in Cosanpa (1.56 NTU) compared to Residencial Tia Ana (0.48 NTU). Both systems had pH levels below the recommended range, reflecting the natural acidity of Amazonian waters. The apparent color was zero in Residencial Tia Ana and varied in Cosanpa. Free residual chlorine was detected only in Cosanpa (1.67 mg/L), indicating effective disinfection. Total coliforms were found in 8.33% of Cosanpa samples and 91.66% of Residencial Tia Ana samples. **Conclusions:** The study highlighted significant differences in water quality between the two systems, with Cosanpa exhibiting better quality due to adequate disinfection, while Residencial Tia Ana showed an urgent need for water treatment and disinfection improvements.

Keywords: Microbiological contamination; Disinfection; Physicochemical parameters; Water supply systems; Water treatment.

RESUMO

Introdução: A avaliação da qualidade da água para consumo humano é essencial para garantir sua adequação e mitigar riscos à saúde, prevenindo doenças transmitidas pela água. **Objetivo**: Avaliar os parâmetros físico-químicos e microbiológicos da água fornecida por dois sistemas públicos em Oriximiná, Pará, Brasil, e identificar variações sazonais nesses parâmetros durante os períodos de seca e cheia. **Metodologia:** O estudo comparou dois sistemas de abastecimento de água: Companhia de Saneamento do Pará (Cosanpa) e Residencial Tia Ana. Amostras de água foram coletadas mensalmente de janeiro a dezembro de 2021 e analisadas quanto a pH, cor aparente, temperatura, turbidez, cloro e coliformes, seguindo procedimentos padronizados. A análise estatística utilizou testes t de Student e t pareado com um nível de significância de 0,05. **Resultados:** A temperatura média não diferiu significativamente entre Cosanpa (22,5°C) e Residencial Tia Ana (22,3°C). A turbidez foi maior na Cosanpa (1,56 NTU) comparado a Residencial Tia Ana (0,48 NTU). Ambos os sistemas apresentaram pH abaixo do recomendado, refletindo a acidez natural das águas amazônicas. A cor aparente foi zero no Residencial Tia Ana e variou na Cosanpa. Cloro residual livre foi detectado apenas na Cosanpa (1,67 mg/L), indicando desinfecção efetiva. Coliformes totais foram encontrados em 8,33% das amostras da Cosanpa e em 91,66% do Residencial Tia Ana. **Conclusões:** O estudo destacou diferenças significativas na qualidade da água entre os dois sistemas, com a Cosanpa apresentando melhor qualidade devido à desinfecção adequada, enquanto Residencial Tia Ana mostrou necessidade urgente de melhorias no tratamento e desinfecção da água.

Palavras-Chave: Contaminação microbiológica; Desinfecção; Parâmetros físico-químicos; Sistemas de abastecimento; Tratamento de água.

RESUMEN

Introducción: La evaluación de la calidad del agua para el consumo humano es esencial para garantizar su adecuación y mitigar riesgos para la salud, previniendo enfermedades transmitidas por el agua. **Objetivo:** Evaluar los parámetros fisicoquímicos y microbiológicos del agua suministrada por dos sistemas públicos en Oriximiná, Pará, Brasil, e identificar las variaciones estacionales en estos parámetros durante los períodos de sequía y de inundación. **Metodología:** El estudio comparó dos sistemas de abastecimiento de agua: Companhia de Saneamento do Pará (Cosanpa) y Residencial Tia Ana. Se recolectaron muestras de agua mensualmente de enero a diciembre de 2021 y se analizaron para pH, color aparente, temperatura, turbidez, cloro y coliformes, siguiendo procedimientos estandarizados. El análisis estadístico utilizó la prueba t de Student y la prueba t pareada con un nivel de significancia de 0,05. **Resultados:** La temperatura media no difirió significativamente entre Cosanpa (22,5°C) y Residencial Tia Ana (22,3°C). La turbidez fue mayor en Cosanpa (1,56 NTU) en comparación con Residencial Tia Ana (0,48 NTU). Ambos sistemas presentaron niveles de pH por debajo del rango recomendado, reflejando la acidez natural de las aguas amazónicas. El color aparente fue cero en Residencial Tia Ana y varió en Cosanpa. El cloro residual libre se detectó solo en Cosanpa (1,67 mg/L), indicando una desinfección efectiva. Se encontraron coliformes totales en el 8,33% de las muestras de Cosanpa y en el 91,66% de las muestras de Residencial Tia Ana. **Conclusiones:** El estudio destacó diferencias significativas en la calidad del agua entre los dos sistemas, con Cosanpa mostrando una mejor calidad debido a una desinfección adecuada, mientras que Residencial Tia Ana mostró una necesidad urgente de mejoras en el tratamiento y desinfección del agua.

Palabras clave: Contaminación microbiológica; Desinfección; Parámetros fisicoquímicos; Sistemas de abastecimiento; Tratamiento del agua.

Introduction

Assessment of water quality for human consumption, focusing on its physical and chemical integrity, is essential for ascertaining its suitability and mitigating health hazards. Compliance with established quality criteria is imperative for public health protection, precluding pathogenic microorganisms and indicators of fecal contamination, thereby averting waterborne diseases[1].

To ensure public health, regulatory frameworks, and procedures govern the treatment of raw water, aiming to align its physical, chemical, and biological properties with human consumption standards. This entails modifying these properties to produce water that is safe for daily use, characterized by the absence of health risks and compliance with established potability criteria, including color, taste, turbidity, pH, and bacteriology[2–4]. Notably, the source of water (fresh or saltwater) is irrelevant; what matters are the stringent regulations and standards set by authorities like the WHO, EPA, EU, and specific national legislations such as Brazil's Ordinance No. 888/2021. These regulations stipulate permissible contaminant levels and outline protocols for water quality assessment and monitoring [4,5]. Given the potential for untreated water to facilitate disease transmission, ensuring the proper treatment of water before distribution is paramount, especially under conditions that might compromise its quality [6].

This study aimed to evaluate the physicochemical and microbiological parameters—specifically, pH, apparent color, temperature, turbidity, chlorine, and coliforms—of water supplied for human consumption via two public systems in Oriximiná, Pará, Amazonia, Brazil. Additionally, it sought to identify seasonal variations in these parameters during drought and flood periods.

Methodology

Study area

Oriximiná, located in the western part of Pará, Brazil is the second-largest municipality in the state, covering an area of 107,602.99 km². The urban center is positioned on the left bank of the Trombetas River (1°45'56" S, 55°51'58" W) and is home to approximately 74,016 people [7]

The region is characterized by an equatorial climate, with average temperatures around 26°C, annual rainfall between 2,000 and 2,500 mm, and high relative humidity levels, typically exceeding 80%. Seasonal variations include pronounced wet periods from March to May and dry spells from August to November [8].

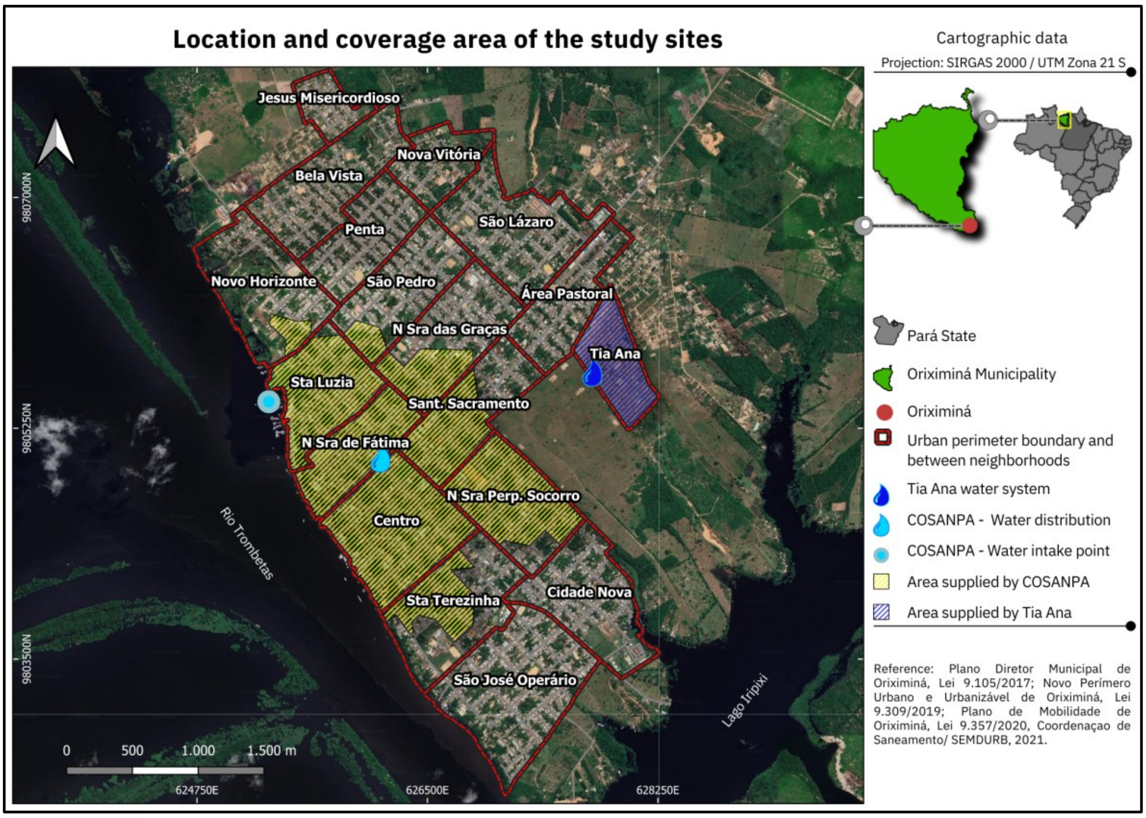
Microsystem Comparison

This study compared two water supply systems in Oriximiná to assess the influence of pre-treatment on water quality:

- ***Companhia de Saneamento do Pará (Cosanpa)***: This is the sole urban water system implementing pre-treatment, sourcing from a surface collection point. It serves about 31.3% of the municipality's permanent residences (PDMO, 2017) (Figure 1).
- ***Residencial Tia Ana***: This system, without prior treatment, draws from an underground source, catering to over 1,000 permanent households (Figure 1).

Field surveys, conducted in collaboration with the municipality's Water Laboratory, established the study points based on treatment processes and source types. This methodology enables a comprehensive analysis of treatment effects on the stipulated water quality parameters.

Figure 1: Map indicating the location and coverage area of the study sites. Oriximiná-PA, 2022.



Source: Prepared by the authors.

Physical-Chemical and Microbiological Analyses

Water samples were systematically collected every month from January to December 2021, from strategically chosen faucets directly linked to the water system's wells or reservoir outlets, to represent the water quality at each study point accurately. Temperature measurements were performed directly at the sampling sites to capture immediate physical conditions. For comprehensive physical-chemical and microbiological evaluation, samples were analyzed following standardized procedures recommended by the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF). The specific parameters assessed in these analyses are detailed in Table 1.

Table 1. Basic parameters of water quality for human consumption evaluated in this work and their respective values established by Brazilian legislation (Normative No. 888/21). Oriximiná-PA, 2022.

Parameters	Standard
Apparent color	15 VMP
Free residual chlorine	0.2 a 2.0 mg/L
pH	6,0 a 9,0
Turbidity	5 MVA*
Temperature	< 33°C
Total coliforms	Absence in 100 ml
Thermotolerant coliforms	Absence in 100 ml

Source: Adapted from Brazil (2021). * MVA- Maximum Value Allowed.

Evaluation of Seasonality Effects on Water Quality Parameters

To assess the impact of seasonality on water quality parameters, our analysis leveraged the distinct seasonal patterns characteristic of the study region. The area predominantly experiences significant rainfall during March, April, and May, and enters a drought phase from August to November. Aligning our sampling strategy with these climatic conditions, we strategically selected water samples from the peak months of both the rainy (March, April, May) and dry (August, September, October) seasons for comparative analysis [8].

Statistical Analysis

The evaluation of parameter averages across the different water supply systems was conducted using the t-Student test for independent samples, complemented by the paired t-test to assess the impact of seasonal variations within each study point. The significance threshold was set at an alpha level of 0.05, corresponding to a 95% confidence interval. All statistical analyses were performed utilizing R-Studio 2019 [9].

Results and Discussion

The assessment of water quality parameters and microbiological data from Cosanpa and Residencial Tia Ana provides a comprehensive overview of the efficacy of water treatment processes and overall water safety in these two systems (Table 2 and Table 3).

The temperatures recorded at Cosanpa (22.5°C) and Residencial Tia Ana (22.3°C) showed no significant difference in their averages ($t = 0.31699$, $df = 21.934$, $p = 0.7542$), indicating effective temperature control across both systems. Seasonal fluctuations were observed, with slightly higher temperatures during the rainy season at Residencial Tia Ana and increased temperatures during drought periods at Cosanpa. However, these variations did not significantly impact the overall temperature averages ($p>0.05$). Consistent temperature management is crucial, as it influences the solubility of minerals, chemical dispersion, and microbial viability, all of which can affect both health risks and the effectiveness of water treatment[10].

Turbidity, which reflects the cloudiness caused by suspended particles, was significantly higher at Cosanpa (1.56 ± 1.4 NTU) compared to Residencial Tia Ana (0.48 ± 0.39 NTU), with a statistically significant difference ($p = 0.009474$). High turbidity levels can signal the presence of particles that might carry pathogens, making disinfection more challenging. Turbidity also complicates drinking water treatment by increasing chemical requirements during coagulation, causing pressure drops in sand filters, and leading to membrane blockages[10]. Despite this difference, both sites maintained turbidity levels within the WHO's guideline of ≤ 5.0 NTU, suggesting effective treatment processes. Seasonal variations showed increased turbidity during the rainy season at both sites, but these differences were not statistically significant ($p>0.05$), indicating stable turbidity management throughout the year and underscoring the effectiveness of water treatment processes in maintaining water quality.

The pH levels at Cosanpa (5 ± 0.69) and Residencial Tia Ana (4.77 ± 0.76) were below the recommended potable range of 6.0 to 9.0[4]. There was no significant difference between the pH levels of the two locations ($p = 0.4728$, $t = 0.73043$), reflecting the naturally acidic conditions of water sources in the Amazon region due to high organic decomposition and rainfall. Although the acidity of water is a common feature in this region, its health implications are less direct but warrant continuous monitoring due to potential interactions with other water quality parameters. Seasonal variations did not significantly affect the pH levels at either site ($p>0.05$), suggesting that seasonal changes do not substantially alter water acidity.

Apparent color, which indicates the presence of suspended solids and organic matter, was zero (0 CU) in all samples from Residencial Tia Ana, meeting the optimal quality standard of 15 CU for drinking water as set by the Ministry of Health. In contrast, Cosanpa's average apparent color was 2.92 ± 4.31 CU, within acceptable limits but showing some variability. Seasonal effects on apparent color at Cosanpa were not statistically significant ($p>0.05$), suggesting that environmental factors have a limited impact on color variations beyond health standards. The consistently low apparent color in Residencial Tia Ana, attributed to natural filtration from its underground water source, indicates effective purification processes. Maintaining low apparent color is important as high color can signify the presence of organic material or contaminants, potentially impacting water quality [11].

Free residual chlorine, a critical parameter for disinfection, was detected exclusively in Cosanpa (1.67 ± 0.24 mg/L), indicating the effectiveness of its water treatment processes in eliminating pathogenic microorganisms and ensuring water potability. The observed chlorine concentrations, ranging from 1.5 to 2.0 mg/L, align with health standards, demonstrating robust disinfection practices[4]. Conversely, Residencial Tia Ana recorded no free residual chlorine, indicating a failure in disinfection and presenting a potential public health hazard. This absence highlights non-compliance with the Ministry of Health Ordinance No. 888, which mandates disinfection for all potable water supplies. The goal of disinfecting public water supplies is to eliminate pathogens responsible for waterborne diseases such as typhoid, paratyphoid fevers, cholera, salmonellosis, and shigellosis. This lack of chlorine at Residencial Tia Ana underscores the urgent need for improved disinfection practices to control the transmission of these diseases by substantially reducing the total number of viable microorganisms in the water [12].

The microbiological analysis revealed significant differences in water quality between the two systems. Total coliforms were detected in 8.33% of Cosanpa samples and 91.66% of Residencial Tia Ana samples. Thermotolerant coliforms and *Escherichia coli* were found in 25% of Residencial Tia Ana samples but absent in Cosanpa samples. These findings indicate a substantial disparity in microbiological quality, with Residencial Tia Ana exhibiting a higher prevalence of potentially harmful microorganisms. This high incidence of coliforms in Residencial Tia Ana suggests deficiencies in water treatment and disinfection, increasing the risk of waterborne diseases. In contrast, Cosanpa's low incidence of coliforms reflects the effectiveness of its water treatment and disinfection processes.

Table 2. Summary of water quality parameters measured at Cosanpa and Residencial Tia Ana, including temperature, turbidity, pH, apparent color, and free residual chlorine, along with corresponding statistical comparisons. Oriximiná-PA, 2022.

Parameter	Cosanpa	Residencial Tia Ana	Statistics
Temperature	22.5°C	22.3°C	t = 0.31699, df = 21.934, p = 0.7542
Turbidity	1.56 ± 1.4 NTU	0.48 ± 0.39 NTU	p = 0.009474
pH	5 ± 0.69	4.77 ± 0.76	t = 0.73043, p = 0.4728
Apparent Color	2.92 ± 4.31 CU	0 CU	p > 0.05
Free Residual Chlorine	1.67 ± 0.24 mg/L	0.0 mg/L	

Source: Prepared by the authors.

Table 3: Results of microbiological analysis carried out on water collected from January to December 2021 in two water distribution systems for human consumption in the municipality of Oriximiná- PA. Oriximiná-PA, 2022.

	Total coliforms (in 100 ml)		**Thermotolerant coliforms *Escherichia coli* (in 100 ml)**	
ID	**Cosanpa**	**Residencial Tia Ana**	**Cosanpa**	**Residencial Tia Ana**
Jan	A	P	A	P
Feb	A	P	A	A
Mar	A	P	A	A
Apr	P	P	A	A
May	A	P	A	P
Jun	A	P	A	A
Jul	A	A	A	A
Aug	A	P	A	A
Sep	A	P	A	A
Oct	A	P	A	P
Nov	A	P	A	A
Dec	A	P	A	A
%	8,33 % Positive	91,66 % Positive	0 % Positive	25 % Positive

Source: Elaborated by the authors. **Note**. A- Ausence; P- Presence.

Conclusion

In summary, our investigation into the water supply systems of Cosanpa and Residencial Tia Ana reveals significant non-compliance with established drinking water standards, underscoring a critical need for intervention by health and regulatory authorities. The disparities observed in microbial contamination, free residual chlorine levels, and physical-chemical parameters such as pH and turbidity signal a broader public health concern that warrants immediate and concerted action.

This study not only highlights the deficiencies in current water treatment and monitoring practices but also opens avenues for further research to identify the root causes of these issues. Collaboration between the academic community and the public sector is vital to devise and implement effective solutions, enhance community awareness regarding water hygiene practices, and ultimately safeguard public health.

We recognize that our study has several limitations that should be acknowledged. The analysis focused on specific physicochemical and microbiological parameters, excluding other potential contaminants such as heavy metals, pesticides, or persistent organic compounds, which may also impact water quality. Additionally, monthly sampling, while suitable for identifying seasonal variations, does not capture daily fluctuations or episodic events, such as heavy rainfall or human interventions, that could influence results. The geographic restriction to Oriximiná limits the generalization of findings to other Amazonian regions, which may exhibit distinct hydrological and socio-environmental dynamics.

For future research, expanding the scope of analyzed parameters to include broader toxicological and chemical assessments, as well as implementing continuous monitoring systems to detect real-time variations, is recommended. Comparative studies in other Amazonian localities, particularly in riverside communities and rural areas, are essential to understanding regional water quality patterns. Integrating accessible technologies, such as portable sensors and digital data-sharing platforms, could strengthen sanitary surveillance and enable rapid responses to emergencies. Concurrently, public policies should prioritize investments in treatment infrastructure, technical training for operators, and educational programs to promote safe water management practices. Collaboration among academic institutions, regulatory bodies, and local communities is critical to ensuring universal access to safe drinking water as a fundamental human right, aligning with the United Nations Sustainable Development Goals (SDGs).

Emphasizing preventive strategies, including the regular maintenance and disinfection of private and public water storage facilities, is imperative to mitigate the risk of waterborne diseases. This research reinforces the necessity of securing access to safe drinking water—a fundamental human right—and calls for sustained efforts to fulfill this essential need across communities.

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