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CHARACTERIZATION OF TUBE WELL WATER IN THE SERTÃO REGION OF BAHIA: CONTAMINANTS, MICROORGANISMS, AND POTABILITY PARAMETERS

CARACTERIZAÇÃO DA ÁGUA DE POÇOS TUBULARES NO SERTÃO BAIANO: CONTAMINANTES, MICRORGANISMOS E PARÂMETROS DE POTABILIDADE

Ana Paula Batista da Silva¹; Ludy Leonor Lima Borges²; Edmundo Marinho Neto³; Ana Lucila Dos Santos Costa⁴; Marcos de Souza Dantas⁵; Kátia Cilene da Silva Félix⁶; Rafaell Batista Pereira⁷; Kaline Catiely Campos Silva⁸; Micherlane Freire de Santana⁹; Ricardo Marques Nogueira Filho¹⁰; Karolayne Silva Souza¹¹; Milena Roberta Freire da Silva¹²

- ¹ University Center of Rio São Francisco (UNIRIOS), Paulo Afonso/BA, Brazil. Email: annynhaa94@outlook.com
ORCID: <https://orcid.org/0009-0002-2723-7692>
- ² University Center of Rio São Francisco (UNIRIOS), Paulo Afonso/BA, Brazil. Email: luhleonor@hotmail.com
ORCID: <https://orcid.org/0009-0000-0083-2710>
- ³ State University of Campinas (UNICAMP), Campinas/SP, Brazil. Email: edmundomarinho@academico.ufs.br
ORCID: <https://orcid.org/0000-0002-3176-3540>
- ⁴ University Center of Rio São Francisco (UNIRIOS), Paulo Afonso/BA, Brazil. Email: ana.costa@unirios.edu.br
ORCID: <https://orcid.org/0000-0001-7618-2371>
- ⁵ University Center of Rio São Francisco (UNIRIOS), Paulo Afonso/BA, Brazil. Email: marcos.dantas@unirios.edu.br
ORCID: <https://orcid.org/0009-0007-7565-0007>
- ⁶ University Center of Rio São Francisco (UNIRIOS), Paulo Afonso/BA, Brazil. Email: katia.felix@unirios.edu.br
ORCID: <https://orcid.org/0000-0003-4791-7177>
- ⁷ Federal University of Alagoas (UFAL), Maceió, AL, Brazil. Email: rafaellspfc@gmail.com
ORCID: <https://orcid.org/0000-0003-4358-4029>
- ⁸ University Center of Rio São Francisco (UNIRIOS), Paulo Afonso/BA, Brazil. Email: kalinnecampos@yahoo.com.br
ORCID: <https://orcid.org/0000-0003-3356-1560>
- ⁹ Federal University of Pernambuco (UFPE), Recife, PE, Brazil. Email: micherlane.santana@unirios.edu.br
ORCID: <https://orcid.org/0009-0001-8904-686X>
- ¹⁰ State University of Bahia (UNEB), Paulo Afonso/BA, Brazil. Email: ricardo.filho@unirios.edu.br
ORCID: <https://orcid.org/0000-0002-7213-7423>
- ¹¹ Federal University of Pernambuco (UFPE), Recife, PE, Brazil. Email: karolayne.silvasouza@ufpe.br
ORCID: <https://orcid.org/0000-0003-2627-7385>
- ¹² Federal University of Pernambuco (UFPE), Recife, PE, Brazil. Email: milena.freire@ufpe.br
ORCID: <https://orcid.org/0000-0003-0203-4506>

Abstract: Groundwater is essential for water supply in semi-arid regions, with tubular wells (boreholes) being a primary source in areas with limited infrastructure. This study evaluated the water quality of ten tubular wells in five villages of Paulo Afonso, Bahia, through physicochemical, microbiological, and parasitological analyses, based on the standards set by Ordinance GM/MS No. 888/2021. Parameters such as pH, chloride, and residual chlorine showed non-compliance in some samples, with a focus on pH values below the permissible level and chloride exceeding the recommended limits. Twenty-two bacteria were identified, including species from the

genera *Bacillus*, *Staphylococcus*, *Serratia*, and *Acinetobacter*, with no occurrence of antimicrobial resistance in the sensitivity tests. The parasitological analysis revealed the absence of protozoa and helminths. The presence of environmental and opportunistic microorganisms suggests a potential health risk, especially due to the possibility of biofilm formation in the pipes. The data indicate the need for continuous monitoring and the adoption of integrated strategies to ensure the safety of the consumed water. The implementation of corrective actions, combined with sanitary education and community involvement, is fundamental to ensuring the potability and sustainable use of groundwater in the region.

Keywords: Rural supply; Bacterial contamination; Potability.

Resumo: As águas subterrâneas são essenciais para o abastecimento em regiões semiáridas, sendo os poços tubulares uma fonte primária em áreas com infraestrutura limitada. Este estudo avaliou a qualidade da água de dez poços tubulares em cinco povoados de Paulo Afonso, Bahia, por meio de análises físico-químicas, microbiológicas e parasitológicas, com base nos padrões da Portaria GM/MS nº 888/2021. Parâmetros como pH, cloreto e cloro residual apresentaram não conformidades em algumas amostras, com destaque para valores de pH abaixo do permitido e cloreto acima dos limites recomendados. Foram identificadas 22 bactérias, incluindo espécies dos gêneros *Bacillus*, *Staphylococcus*, *Serratia* e *Acinetobacter*, sem ocorrência de resistência antimicrobiana nos testes de sensibilidade. A análise parasitológica revelou ausência de protozoários e helmintos. A presença de microrganismos ambientais e oportunistas sugere risco potencial à saúde, especialmente pela possibilidade de formação de biofilmes nas tubulações. Os dados indicam a necessidade de monitoramento contínuo e adoção de estratégias integradas para garantir a segurança da água consumida. A implementação de ações corretivas, aliadas à educação sanitária e ao envolvimento comunitário, é fundamental para assegurar a potabilidade e o uso sustentável das águas subterrâneas na região.

Palavras-chave: Abastecimento rural; Contaminação bacteriana; Potabilidade.

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1. Introduction

Groundwater plays an essential role in providing drinking water, particularly in regions facing surface water scarcity or lacking centralized public distribution systems. In these contexts, tubular wells emerge as critical infrastructure, being widely utilized across both rural and urban areas (FILHO *et al.*, 2019). Within the Northeastern Brazilian semi-arid region, specifically in Paulo Afonso, Bahia, these wells represent a vital alternative for the supply of potable water to consumers.

In Brazil, the quality of water intended for human consumption is regulated by specific legislation that establishes potability standards and guidelines for contamination control. For instance, Ordinance GM/MS No. 888, issued on May 4, 2021, by the Ministry of Health, consolidates the procedures and responsibilities regarding the surveillance of water quality for human consumption (BRASIL, 2021). Additionally, regarding groundwater resources, Resolution No. 396, issued on April 3, 2008, by the National Environmental Council (CONAMA), establishes the conditions and standards for the classification and use of these resources, considering their intended purpose, including public supply (BRASIL, 2008).

The present study aimed to evaluate the water quality of tubular wells in the municipality of Paulo Afonso, Bahia, through the analysis of physicochemical, microbiological, and parasitological parameters. These analyses were conducted based on the potability standards established by Brazilian legislation to identify potential contaminations that may pose risks to public health.

2. Methodology

Study Area and Sample Collection

Water samples were collected from five distinct villages in the municipality of Paulo Afonso, Bahia, designated as M1 to M5. A total of 10 samples were obtained from tubular wells used for human consumption. Subsequently, the sampling points were georeferenced using Google Earth Pro software (Figure 1), with the coordinates presented as follows:

- Village 1 - (-9.4296587, -38.4191322)

- Village 2 - (-9.55052, -38.44176)
- Village 3 - (-9.5480778, -38.4067065)
- Village 4 - (-9.50599, -38.36514)
- Village 5 - (-9.32550, -38.26064)



Figure 1. Geographical location of the sampled villages in the municipality of Paulo Afonso, BA. Source: Prepared by the authors based on Google Earth Pro data (2025).

Sample Collection

Samples were collected in 500 mL polyethylene bottles, previously autoclaved. Aseptic procedures were strictly followed during collection to prevent exogenous contamination and ensure the microbiological integrity of the samples. Following collection, samples were immediately placed in isothermal containers and transported to the Microbiology Laboratory at the University Center of Rio São Francisco (UNIRIOS).

Physicochemical Analysis

Physicochemical analyses were performed for the following parameters: alkalinity (mg/L), ammonia (mg/L), chloride (mg/L), total hardness (mg/L), free/residual chlorine (DPD), and pH. Determinations were conducted using the Alforkit Basic Potability kit, strictly following the manufacturer's instructions.

Bacterial Isolation

Aliquots of 100 μ L from each sample were inoculated via surface plating onto Blood Agar and Brain Heart Infusion (BHI) broth. Inoculation was performed using a Drigalski spatula under aseptic conditions within a laminar flow hood. The plates were incubated in a bacteriological incubator at 36.5 °C for 24 to 48 hours to promote the growth of viable bacterial colonies. Following incubation, colonies with distinct morphologies underwent successive subculturing on solid media to obtain pure cultures for subsequent identification.

Bacterial Identification

Pure isolates were sent to the Federal University of Pernambuco (UFPE) for microbiological identification via Matrix-Assisted Laser Desorption/Ionization-Time of Flight Mass Spectrometry (MALDI-TOF MS). Each sample was subjected to laser ionization, releasing molecular fragments separated by their mass-to-charge ratio (m/z). The mass spectra were automatically compared against the system's reference library. Results were expressed as log(score) values; according to literature and manufacturer recommendations, scores > 2.0 were considered reliable for species-level identification.

Antimicrobial Susceptibility Testing

Susceptibility was evaluated using the disk diffusion method (Kirby-Bauer technique), standardized according to the Clinical and Laboratory Standards Institute (CLSI, 2025) guidelines. Isolates were transferred to Mueller-Hinton Agar plates and incubated at 36 °C for 48 hours. Subsequently, colonies were suspended in 4 mL of 0.85% sterile saline solution and adjusted to achieve uniform lawn growth using a sterile swab.

The following antimicrobial disks were applied: Oxacillin (1 µg), Gentamicin (10 µg), Clindamycin (2 µg), Ampicillin (10 µg), Nalidixic Acid (30 µg), Cefotaxime (30 µg), Rifampicin (5 µg), Penicillin (10 UI), Imipenem (10 µg), Tetracycline (30 µg), Erythromycin (15 µg), and Streptomycin (10 µg).

After incubation at 35 °C for 24 hours, inhibition zone diameters were measured with a precision caliper and classified as susceptible, intermediate, or resistant based on CLSI (2025) breakpoints.

Parasitological Analysis

The spontaneous sedimentation technique (Hoffman, Pons, and Janer method) was utilized with adaptations. Samples (100 mL) were homogenized and allowed to settle for 24 hours. The resulting sediment was then collected and analyzed as described by Póvoas *et al.* (2020).

3. Results and discussion

Physicochemical analyses

The physicochemical analyses conducted on the water samples collected across the five investigated villages (Village 1 to Village 5) yielded values comparable to the potability limits defined by Ordinance GM/MS No. 888/2021, except for specific instances where parameters exceeded the permissible levels. Table 1 presents the values obtained for each parameter, the respective collection sites, and the limits established by the regulations.

Table 1. Analysis of physicochemical parameters in water samples from five villages in Paulo Afonso, Bahia.

Parameter	Sample										Limits (Standard)
	Village 1.1	Village 1.2	Village 1.3	Village 2.1	Village 2.2	Village 3.1	Village 3.2	Village 4.1	Village 4.2	Village 5	
pH	6,0	6,0	6,0	5,0	5,0	5,0	5,0	7,0	7,0	7,0	6,0 e 9,5

Alkalinity (mgL ⁻¹ CaCO ₃)	30	40	20	30	30	20	20	170	180	160	75 - 200 mg/L
Chloride (mgL ⁻¹ Cl)	120	100	200	100	100	460	450	140	140	270	250 mg/L
Total Hardness (mgL ⁻¹ CaCO ₃)	100	120	160	100	125	260	210	200	200	400	500 mg/L
Ammonia (mg L ⁻¹ NH ₃)	1,214	1,214	1,214	1,214	1,214	1,214	1,214	1,214	1,214	1,214	1,5 mg/L
Free Residual Chlorine (DPD)	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,2-5,0 mg/L

Source: Prepared by the authors.

The physicochemical analyses performed on the water samples from the tubular wells revealed significant variations among the evaluated parameters. pH values ranged from 5.0 to 7.0, with samples Pov 2.1, Pov 2.2, Pov 3.1, and Pov 3.2 presenting values below the minimum limit established by Ordinance GM/MS No. 888/2021, which mandates a range of 6.0 to 9.5 for water intended for human consumption. Regarding total alkalinity, the results varied from 20 to 180 mg/L CaCO₃, with values distributed within or near the reference interval of 75 to 200 mg/L. Chloride levels showed a range of 100 to 460 mg/L; notably, three samples: Pov 3.1, Pov 3.2, and Pov 5, exceeded the maximum limit of 250 mg/L established by the same regulation. As for total hardness, the values obtained fluctuated between 100 and 400 mg/L CaCO₃, remaining below the maximum permissible value of 500 mg/L. For the ammonia parameter, all samples exhibited a constant concentration of 1.214 mg/L NH₃, situated below the 1.5 mg/L limit. Finally, free residual chlorine levels were uniform across all samples, with a concentration of 0.10 mg/L, which is lower than the minimum recommended value of 0.2 mg/L.

Análises microbiológicas

In the analyzed samples, 22 bacterial isolates were identified across five villages, consisting of 9 (41%) Gram-positive and 13 (59%) Gram-negative bacteria. The distribution of isolates by village was as follows: Village 1 presented 7 isolates (32%), Village 2 had 4 isolates (18%), Village 3 accounted for 2 isolates (9%), Village 4 with 5 isolates (23%), and Village 5 presented 3 isolates (14%), as shown in Table 2.

Table 2. Bacterial characterization by MALDI-TOF MS of isolates from different villages.

Sample	Identification	Score
Village 1	<i>Bacillus koreensis</i>	2.10
	<i>Acinetobacter lwoffii</i>	2.01
	<i>Staphylococcus hominis</i>	2.33
	<i>Salmonella sp</i>	2.03
	<i>Serratia marcescens</i>	2.00
	<i>Serratia marcescens</i>	2.04
	<i>Staphylococcus hominis</i>	2.39
Village 2	<i>Bacillus marisflavi</i>	2.20
	<i>Bacillus megaterium</i>	2.22
	<i>Bacillus koreensis</i>	2.15
	<i>Bacillus mojavensis</i>	2.18
Village 3	<i>Plesiomonas shigelloides</i>	2.11
	<i>Micrococcus luteus</i>	2.38
Village 4	<i>Staphylococcus epidermidis</i>	2.15
	<i>Pseudomonas alcaligenes</i>	2.14
	<i>Pantoea septica</i>	2.12
	<i>Acinetobacter lwoffii</i>	2.08
	<i>Acinetobacter junii</i>	2.19
Village 5	<i>Staphylococcus caprae</i>	2.03

Bacillus megaterium 2.05

Ralstonia pickettii 2.06

Source: Prepared by the authors.

Both Gram-positive and Gram-negative microorganisms were identified, with a notable prevalence of the genus *Bacillus*, present in four out of the five villages, including the species *Bacillus koreensis*, *Bacillus megaterium*, *Bacillus marisflavi*, and *Bacillus mojavensis*. Among the Gram-positive bacteria, species of the genus *Staphylococcus* were also recurrent, with the identification of *Staphylococcus hominis*, *Staphylococcus epidermidis*, and *Staphylococcus caprae* at different sites.

In Village 1, species such as *Bacillus koreensis*, *Acinetobacter lwoffii*, *Staphylococcus hominis*, *Salmonella* sp., and *Serratia marcescens* were detected, indicating a diversity of both Gram-positive and Gram-negative bacteria. Village 2 presented isolates exclusively from the genus *Bacillus*, comprising four different species. Village 3 revealed the presence of *Plesiomonas shigelloides* and *Micrococcus luteus*. Village 4 exhibited a higher bacterial variety, including *Staphylococcus epidermidis*, *Pseudomonas alcaligenes*, *Pantoea septica*, and two species of *Acinetobacter*. In Village 5, *Staphylococcus caprae*, *Bacillus megaterium*, and *Ralstonia pickettii* were identified.

The score values obtained via the MALDI-TOF MS technique were greater than 2.0 for all species, ensuring high reliability for identification at the species level. The bacterial composition presents a diversified profile, highlighting the coexistence of different genera that may be related to both natural environments and potential sources of contamination. Furthermore, the parasitological analysis of the water samples from the five evaluated villages yielded negative results for the presence of parasite evolutionary forms.

Regarding the antibiotic susceptibility tests, all 22 isolates presented inhibition zones equal to or greater than the CLSI (2025) sensitivity breakpoints for each tested antibiotic, as detailed below (values in mm): Oxacillin \geq 13, Gentamicin \geq 15, Clindamycin \geq 21, Ampicillin \geq 17, Nalidixic Acid \geq 19, Cefotaxime \geq 18, Rifampicin \geq 20, Penicillin \geq 29, Imipenem \geq 23, Tetracycline \geq 19, Erythromycin \geq 23, and Streptomycin \geq 15. These data are consolidated in Table 3, reinforcing the low occurrence of bacterial resistance in the studied tubular well water samples.

Table 3. Antibiotics tested and sensitivity breakpoints (mm).

Microrganism	Antibiotics tested (breakpoint \geq mm)
<i>Staphylococcus hominis</i>	Oxacillin \geq 13; Gentamicin \geq 15; Clindamycin \geq 21
<i>Salmonella</i> sp.	Ampicillin \geq 17; Nalidixic Acid \geq 19; Cefotaxime \geq 18
<i>Staphylococcus epidermidis</i>	Oxacillin \geq 13; Rifampicin \geq 20; Penicillin \geq 29
<i>Pseudomonas alcaligenes</i>	Imipenem \geq 23; Gentamicin \geq 15; Tetracycline \geq 19
<i>Micrococcus luteus</i>	Penicillin \geq 29; Erythromycin \geq 23; Rifampicin \geq 20
<i>Acinetobacter junii</i>	Imipenem \geq 23; Gentamicin \geq 15; Ampicillin \geq 17
<i>Serratia marcescens</i>	Cefotaxime \geq 18; Imipenem \geq 23; Tetracycline \geq 19

*Ralstonia pickettii*Ampicillin ≥ 17 ; Clindamycin ≥ 21 ; Streptomycin ≥ 15

Source: Prepared by the authors.

In this study, a portion of the analyzed samples exhibited physicochemical parameters outside the potability standards established by Ordinance GM/MS No. 888/2021 (Brazil, 2021), in addition to the presence of potentially pathogenic microorganisms. Consequently, these findings indicate a clear need for corrective actions and continuous monitoring.

The pH of the analyzed samples ranged between 5.0 and 7.0, with four samples presenting values below the minimum permitted limit (6.0). Water acidity, often associated with soil composition, can significantly influence the corrosion of metallic pipes, compromising infrastructure integrity and potentially affecting the quality of the supplied water (CASTRO, 2013).

Regarding total hardness, the results were within regulatory limits, ranging from 100 to 400 mg/L (below the 500 mg/L threshold), indicating satisfactory quality for this parameter. Conversely, high chloride levels are frequently associated with contamination from human activities, such as domestic sewage infiltration, fertilizer use, or natural salinization (DELAUNAY *et al.*, 2024; SHUBO; FERNANDES; MONTENEGRO, 2020).

On a positive note, antimicrobial susceptibility tests conducted on several strains showed no evidence of resistance to the tested antibiotics. This demonstrates that, despite the presence of environmental and pathogenic microorganisms, the evaluated aquatic environment does not currently exhibit significant selective pressure for microbial resistance. However, the literature warns that aquatic environments can act as reservoirs and dissemination routes for resistance genes, especially where there is indiscriminate use of antibiotics in humans or animals (YANG *et al.*, 2025; SINGH *et al.*, 2022; CHEUNG *et al.*, 2025).

Beyond the aforementioned aspects, the microbial diversity identified in this work suggests the existence of various ecological niches within the tubular wells. This heterogeneity is associated not only with local geology but also with interactions between groundwater and the water table, favoring the formation of micro-communities adhered to the well walls, which may lead to biofilms.

The formation of biofilms in drinking water supply systems represents a critical challenge to microbiological quality, as these communities allow pathogens to persist even after disinfection (QUINTELA, 2016). Studies indicate that physicochemical flow factors, such as velocity and piping composition, directly influence the dynamics of biofilm adherence and detachment, generating fluctuations in bacterial load and sanitary risk (LAMON, 2020).

In this context, when present, these biofilms act as pathogen reservoirs and can reduce the efficiency of subsequent treatments, reinforcing the importance of regular mechanical cleaning and facility sanitization (ALMEIDA *et al.*, 2019). Regarding the evaluated water samples, parasitological tests were negative for the presence of protozoa and helminths in all tubular well samples. This finding suggests that, for the evaluated parasitic microorganisms, the collected water met the minimum standards required for human consumption. This result aligns with studies such as Correia *et al.* (2022), conducted in a Quilombola community in Alagoas, where no infectious forms of parasites were detected in water analyses despite observed alterations in physical and microbiological parameters.

Although our results did not detect resistant strains in the sensitivity tests, environmental monitoring studies highlight the occurrence of antibiotic residues in surface and groundwater—even at sub-nanomolar concentrations—capable of selecting for resistance genes over the long term (CANEDO, 2024). Furthermore, seasonal variability plays an important role in water quality; in semi-arid regions, intense rainfall can alter turbidity, transport organic matter and parasites to the water table, and dilute chemical contaminants, while drought periods increase the concentration of ions and pharmacochemical residues (MEDEIROS, 2016).

4. Conclusion

In conclusion, the present study demonstrated that while most physicochemical parameters (turbidity, total dissolved solids, nitrate, and fluoride) aligned with the potability standards of Ordinance GM/MS No. 888/2021, certain samples exhibited pH levels below 6.0 and chlorides exceeding 250 mg/L. These findings signal a need for specific adjustments in the treatment and management of the wells. The microbiological analysis revealed a diversity of environmental and

opportunistic bacteria; although no resistance to the 12 tested antibiotics was observed, the potential for biofilm formation within the pipelines remains a concern.

Therefore, the implementation of a multiple-barrier system is recommended, combined with sanitary education, community engagement, and the conduction of sampling across the entire hydrological cycle. These integrated actions are fundamental to ensuring potability, preserving infrastructure, and guaranteeing the sustainable use of groundwater in the semi-arid region of Bahia. These findings reinforce the necessity of a continuous and multifaceted surveillance program in Paulo Afonso, aligning physicochemical, microbiological, and pharmaceutical monitoring with appropriate treatment strategies and community involvement to ensure the safety and sustainability of groundwater resources.

adequadas e ao engajamento da comunidade para assegurar a potabilidade e a sustentabilidade dos recursos hídricos subterrâneos.

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