POTABILITY OF GROUNDWATER IN ALTERNATIVE SYSTEMS IN THE INTERIOR OF MARANHÃO: A CASE STUDY IN CODÓ-MA

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ABSTRACT

The quality of water intended for human consumption is one of the main determinants of public health, especially in rural communities with limited access to basic sanitation. This study evaluated the potability of water from three types of wells (cacimba, artesian and cacimbão) located in the village of Matões dos Moreiras, in the municipality of Codó, Maranhão. Physicochemical, microbiological and sensory analyses were carried out, based on the parameters established by Ordinance GM/MS No. 888/2021. The results revealed multiple non-conformities in relation to the maximum allowed values for several parameters, such as total hardness, turbidity, apparent color, presence of chromium, iron and absence of residual chlorine. The microbiological analysis showed the presence of total coliforms in all samples and the detection of Escherichia coli in two of the three wells evaluated, indicating recent fecal contamination and compromised water safety. The sensory characterization also revealed odor outside the acceptability standards, especially in the bucket well, with averages higher than the allowed limit. The presence of sulfur compounds, iron and manganese may explain part of the odors detected. These results highlight the sanitary vulnerability of groundwater sources used by the local population and point to the need for structural interventions, continuous disinfection and regular monitoring of water quality. The study reinforces the importance of public policies aimed at community water management, basic sanitation and equitable access to drinking water in rural areas, contributing to the reduction of water risks and promotion of environmental health.

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INTRODUCTION

Water, an essential element for life, has been the subject of growing concern around the world. The growing demand for this resource, combined with environmental degradation and climate change, has intensified the search for alternative sources of supply and the need to ensure the quality of water available for human consumption (Rutkowski; Lane; Oliveira, 1999; Peil; Kuss; Gonçalves, 2015). In this context, the assessment of water quality in non-conventional supply systems, such as wells, becomes fundamental for the protection of public health.

In Brazil, water scarcity and water quality are persistent challenges, especially in rural areas. Many communities rely on wells as their only source of supply, which makes analyzing the water quality of these systems essential to ensure the health of the population (Soares et al., 2020). Ordinance GM/MS No. 888, of May 4, 2021, establishes the standards for the potability of water for human consumption in Brazil, providing an important reference for the assessment of water quality (Brasil, 2021; Oliveira Junior; Silva; Prado, 2023).

Access to safe and treated drinking water is still a challenge in many areas of Brazil, especially in rural areas. In these regions, where basic sanitation infrastructure is limited, water contamination by pathogenic microorganisms becomes a significant concern. Lack of adequate surveillance and the use of untreated sources of supply, such as community wells, increase the risk of waterborne diseases, directly affecting the health of the local population (Sperling, 2007; Ayach et al. 2009; Coast; Suda; Pinto, 2024).

It is crucial to focus on water quality, as several historical events reveal that some of the largest outbreaks that have impacted the human population originated in water distribution systems. Progress in development is closely linked to the relationship between water and health, as water is fundamental to human well-being. The connection between water, hygiene and health is a concept that has accompanied humanity since the earliest stages of civilization (Alves; Ataíde; Silva, 2018).

Water contamination by pathogenic microorganisms, such as *Escherichia coli*, can cause a variety of diseases, including diarrhea, gastroenteritis, and urinary tract infections. In addition, the presence of chemical contaminants in water can have long-term health effects, such as the development of chronic diseases (Macedo et al., 2021; P; Souza, 2018).

In Maranhão, the quality of water in supply systems, especially in rural areas, is a topic of great relevance. Previous studies carried out in the state (Sousa et al., 2016; Coelho et al., 2017, Lira; Gonçalves, 2022; Olive tree; Olive tree; Zaidan, 2025) evidenced the presence of contaminants in several water sources, highlighting the need for continuous monitoring of water quality to ensure the health of the population.

The municipality of Codó, located in Maranhão, has a significant portion of the population that depends on wells for water supply. However, the quality of the water from these wells is still poorly known, which may pose a health risk to the local population.

Understanding the quality of the water from the wells in this region is essential for the implementation of measures to control and improve the quality of the water, thus ensuring the health of the local population and contributing to the sustainable development of the region.

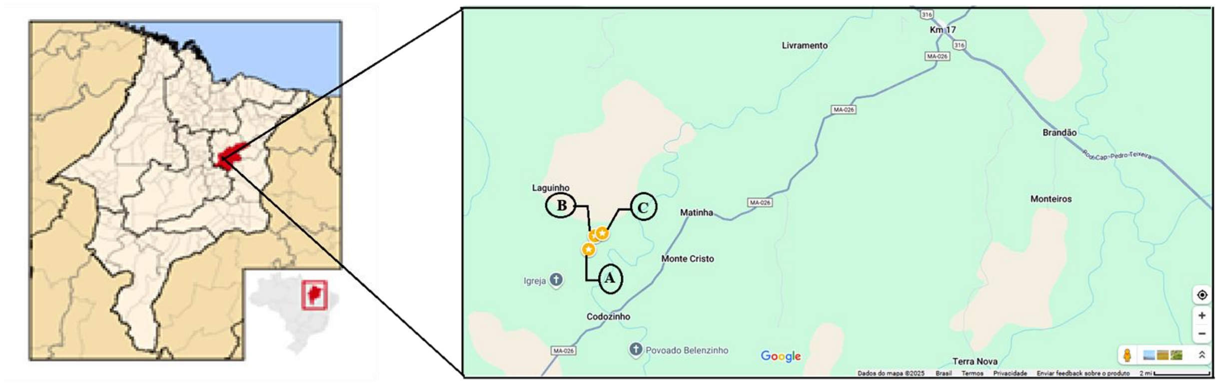
In view of this scenario, the present study aimed to evaluate the water quality of wells used for human consumption in the village of Matões dos Moreiras, located in the municipality of Codó-MA. Physicochemical, microbiological and sensory analyses (odor and taste) of the water samples were carried out in order to verify compliance with the standards established by the Brazilian legislation.

METHODOLOGY

GEOGRAPHICAL LOCATION OF THE WELLS

The location of points by GPS (Global Positioning System) was used through the Garmin Etrex® 10 programmed for the UTM (Universal Transverse Mercator) coordinate parameter, and it was necessary to convert the values to the geographic coordinate parameter in the format of degrees, minutes and seconds (GMS) for the launch of the points on the Google Maps website. The application used to convert the UTM coordinates to geographic was "Geographic Calculator" from the Image Processing Division (DPI) of the National Institute for Space Research (INPE). Figure 1 and Chart 1 show the locations of the wells and coordinates, respectively.

Figure 1. Collection sites Cacimba (A), Artesiano (B) and Cacimbão (C) in Matões dos Moreiras, Codó-MA.



Source: Google Maps (2025), with adaptation.

Table 1. Geographic coordinates of the wells in Matões dos Moreiras, Codó-MA.

Geographic Coordinate: Degrees, Minutes, Seconds (GMS)		
Well	**Longitude**	**Latitude**
Bucket	44º10'52.3" W	4º40'39.8" S
Artesian	44º10'40.4" W	4º40'14.4" S
Cacimbão	44º10'26.4" W	4º40'09.1" S

Source: The authors (2025)

SAMPLE COLLECTION

The collections of each sample were made in triplicate, and the methodology used is the National Guide for Sample Collection and Preservation of ANA/CETESB. The collections were carried out in February 2017. For the collection, a borosilicate bottle previously sterilized in an autoclave, sterile Whirl Pack® bags for microbiological test samples and sterilized polyethylene bottles for physicochemical tests were used, both identified and after collection packed in different thermal containers and refrigerated between -2ºC and -4ºC and taken within 24 hours to the CERNITAS laboratory in São Luís-MA, and to the Federal Institute of Maranhão, São Luís-Monte Castelo Campus, for analytical tests.

The samples were collected from three wells, as shown in Figure 2: cacimba (A) (structured with a shackle at its opening), artesian (B) and cacimbão (C), respectively.

Figure 2. Types of Wells Used for Water Collection: Cacimba (A), Artesian (B) and Cacimbão (C).

Source: The authors (2025)

PHYSICOCHEMICAL ANALYSIS OF WELL WATER

The analyses for the physicochemical characterization of the water from the wells of the present study (Table 1) followed the standard methodologies established in *the Standard Methods for the Examination of Water and Wastewater* (APHA, 2005).

Table 1. Physicochemical analysis of the waters of the Cacimba (A), Artesiano (B) and Cacimbão wells and respective methodologies used.

PARAMETER	METHODOLOGY
pH, temperature, electrical conductivity, and total dissolved solids (STD)	Potentiometric
Free Residual Chlorine	UV-Vis molecular absorption spectrometry
Apparent color	Visual colorimeter with fluorescent light base
Turbidity	Nephelometric test method, using a turbidimeter
Chlorides	Precipitation titration using the Mohr method
Total hardness, calcium and magnesium	Complexiometric titration
Alkalinity	Acid-base titralometry
Anions and Cations	Photometry (ALFAKIT)®

Source: The authors (2025)

MICROBIOLOGICAL ANALYSES OF WELL WATER

For the qualitative analysis of total coliforms and *Escherichia coli* (E. coli) in the water samples, the chromogenic and fluorogenic method COLILERT® (IDEXX) was adopted. This method is based on the identification of microorganisms by detecting the enzymes they produce (Ramoutar, 2020; França et al., 2021), and is approved by *the Standard Methods for the Examination of Water and Wastewater*.

The parameters were compared according to the basic potability, intended for human consumption required in Ordinance GM/MS No. 888, of May 4, 2021, as well as the verification of the results of the analyses, the VMP (maximum allowed values) of the same ordinance were used.

a. 2.5 SENSORY ANALYSIS OF WELL WATER

To determine odor, the smell technique was used, according to the methodology of Ferreira Filho and Alves, (2006) through a sensory panel with 6 classifications (exempt (0), threshold (2), weak (4), weak and moderate (6), moderate (8), moderate and strong (10) and strong (12); where 6 is the maximum allowed value (VMP) of PRC No. 5/2017), it was later translated into the Wheel of Taste and Odor (Figure 5) as proposed by Mautone and Kazuko (2004, *apud* Ferreira Filho; Alves, 2006).

Figure 5. Taste and odor wheel used to classify the water collected in the wells of Matões dos Moreiras, Codó, MA.

Source: Mautone and Kazuko (2004, *apud* Ferreira Filho; Alves, 2006)

RESULTS

PHYSICOCHEMICAL PARAMETERS

Table 2 shows that the pH values of the three sources ranged from 6.20 to 7.69, all within the acceptable range of 6 to 9.5 established by the legislation. Recent studies indicate that groundwater pH can vary significantly depending on local geology and anthropogenic activities. For example, Müller et al. (2022) observed pH variations between 5.8 and 7.4 in wells in the southern region of Brazil, influenced by geological composition and land use.

Table 2. Results of the physicochemical analyses carried out in the field.

Parameter	Wells		
	Bucket	**Artesian**	**Cacimbão**
ph	6.20 ± 0.00	6.85 ± 0.00	7.69 ± 0.00
STD (mg/L)	293.00 ± 0.00	1,326 ± 0.00	68.00 ± 0.00
Temperature (ºC)	26.60 ± 0.00	28.50 ± 0.00	26,50 ± 0,00
Electrical Conductivity (µS)	572.00 ± 0.00	2,611 ± 0.00	135.00 ± 0.00
Residual Chlorine (mg/L)	0,00	0,00	0,00

Source: The authors (2025)

The values of Total Dissolved Solids (STD) were 293.0 mg/L for the well, 1,326 mg/L for the artesian well and 68 mg/L for the well. Total dissolved solids are composed of particles with a diameter of less than 10^{-3} µm and constitute a parameter of water potability, as their presence may be related to contamination by sewage and cause changes in organoleptic characteristics, resulting in consumer rejection (Bezerra et al., 2018; Brazil, 2021). Among the samples analyzed, the artesian well showed a STD value significantly higher than the limit established by Ordinance GM/MS No. 888/2021 (Brasil, 2021), which is

1,000 mg/L for drinking water, indicating potential compromise of water quality and possible need for treatment before consumption. This high value may reflect natural processes of mineral leaching or, more worryingly, anthropogenic influence, such as effluent infiltration or improper waste disposal in urban areas.

The electrical conductivity varied significantly, with values of 572 μS for the well, 2611 μS for the artesian well and 135 μS for the well. The high conductivity in the artesian well can be attributed to the presence of dissolved salts, often associated with agricultural and industrial activities. According to Alkarkhi et al. (2008), electrical conductivity in groundwater can range from 100 to 3000 μS, depending on the concentration of dissolved ions.

The absence of residual chlorine in the water samples of the cacimba, artesian and cacimbão wells, as observed in their analysis, is a common characteristic in groundwater not submitted to disinfection processes. However, this absence represents a potential risk to public health, as residual chlorine is essential to inhibit the proliferation of pathogenic microorganisms. A study conducted by Santos et al. (2024) in the municipality of Itabaiana, Sergipe, evaluated the potability of water from artesian wells and found that all samples had free residual chlorine levels below the minimum established by Ordinance GM/MS No. 888/2021. This deficiency was correlated with the presence of fecal coliforms and Escherichia coli, indicating microbiological contamination and unsuitability for human consumption. These findings underscore the importance of implementing effective disinfection systems and continuous monitoring of water quality, even in underground sources, to ensure sanitary safety and meet the potability standards established by current legislation.

Table 3 shows the results of the physicochemical analyses carried out in the laboratory. The values obtained indicate possible contamination by organic or inorganic matter, which can compromise the aesthetic and microbiological quality of the waters. The comparison with the maximum values allowed by Ordinance GM/MS No. 888 reveals that, while some parameters are within acceptable limits, others, such as total hardness, turbidity, apparent color and chromium, exceed the recommended values, indicating the need for treatment and continuous monitoring to ensure the potability and safety of groundwater.

Table 3. Results of the physicochemical analyses carried out in the laboratory of the water from the wells.

Parameter	VMP*	Bucket	Artesian	Cacimbão
Chloride (mg/L)	250	158.40 ± 0.00	87.12 ± 0.00	21.78 ± 0.00
Total Alkalinity (mg/L)	-	30.52 ± 0.00	299.38 ± 0.00	34.88 ± 0.00

Total Hardness (mg/L)	500,00	75.24 ± 0.00	**1767.48** ± 0.00	0.00 ± 0.00
Calcium (mg/L)	-	12.70 ± 0.00	561, 85 ± 0.00	0.00 ± 0.00
Magnesium (mg/L)	-	10.60 ± 0.00	88.60 ± 0.00	0.00 ± 0.00
Turbidity (uT)	5,00	**11.30** ± 0.60	1.13 ± 0.01	**438** ± 6.36
Apparent Color (uH)	15,00	**20,00** ± 0,00	2.50 ± 0.00	**1.200,00** ± 0,00
Manganese (mg/L)	0.10	0.09 ± 0.00	0.19 ± 0.01	**0.51** ± 0.02
Nitrite (mg/L)	1,00	0.00 ± 0.00	0.07 ± 0.00	0.32 ± 0.00
Nitrate (mg/L)	10,00	0.47 ± 0.06	0.13 ± 0.03	1.52 ± 0.06
Ammonia (mg/L)	1,50	0.00 ± 0.00	0.00 ± 0.00	0.49 ± 0.00
Zinc (mg/L)	5,00	0.00 ± 0.00	0.00 ± 0.00	1.99 ± 0.01
Chromium (mg/L)	0,05	**0.25** ± 0.00	**0.24** ± 0.00	**4.03** ± 0.05
Sulphate (mg/L)	250,00	7.78 ± 0.30	**945.66** ± 0.25	93.89 ± 1.45
Sulfide (mg/L)	0,10	0.08 ± 0.00	0.00 ± 0.00	**0.56** ± 0.00
Fluoride (mg/L)	1,50	0.19 ± 0.00	0.85 ± 0.01	0.00 ± 0.00
Copper (mg/L)	2,00	0.19 ± 0.01	0.25 ± 0.01	0.14 ± 0.01
Aluminum (mg/L)	0,20	0.12 ± 0.01	0.00 ± 0.00	**1.41** ± 0.01
Surfactants (mg/L)	0,50	0.49 ± 0.00	0.36 ± 0.02	0.18 ± 0.00
Total Iron (mg/L)	0,30	0.11 ± 0.01	0.12 ± 0.00	**3.43** ± 0.06

*VMP: Maximum amounts allowed according to the legislation.
Source: The authors (2025)

The chloride values in the samples ranged from 21.78 mg/L to 158.40 mg/L, all within the maximum allowed limit (MPV) of 250.00 mg/L. Recent studies, such as that of Müller et al. (2022), indicate that the concentration of chlorides in groundwater can be influenced by the proximity of sources of saline contamination.

The total alkalinity presented values of 30.52 mg/L in the well, 299.38 mg/L in the artesian well and 34.88 mg/L in the well. Although the ordinance does not establish a specific VMP for alkalinity, it is important to monitor this parameter, as it influences the buffering capacity of water and its corrosivity.

The total hardness ranged from 0.00 mg/L in the bucket to 1767.48 mg/L in the artesian well, with the bucket presenting 75.24 mg/L. The MPV for total hardness is 500.00 mg/L, and the artesian well significantly exceeded this value, indicating a high concentration of calcium and magnesium ions, which can affect palatability and scale formation in distribution systems.

The values of calcium and magnesium also reflect this variation, with the artesian well showing concentrations of 561.85 mg/L of calcium and 88.60 mg/L of magnesium, while the other sources showed significantly lower values. The high concentration of these ions in the artesian well can be attributed to the dissolution of minerals present in the local geological formations. Alkarkhi et al. (2020) highlight that the presence of high levels of these ions is common in areas with limestone rocks

Turbidity and apparent color showed significant variations, with the cacimbão showing extremely high values (438 uT of turbidity and 1200 uH of apparent color), both exceeding the VMP's of 5 uT and 15 uH, respectively. These values indicate possible contamination by organic or inorganic matter, which can compromise the sensory and microbiological quality of the water.

The levels of manganese, nitrite, nitrate, ammonia, zinc, chromium, sulfate, sulfide, fluoride, copper, aluminum, surfactants and total iron were also analyzed. In particular, chromium presented values above the allowed limit (0.05 mg/L) in all sources, with cacimbão showing the highest value (4.03 mg/L). The presence of chromium at high levels can be attributed to industrial and agricultural activities in the region, representing a potential health risk, and there is a need for continuous monitoring and control measures to ensure the safety of the water consumed.

The results indicated significant variations in the physicochemical parameters of the different groundwater sources. Comparison with literature data reveals that factors such as geographic location and human activities directly influence water quality.

MICROBIOLOGICAL PARAMETERS

Based on the data presented in Table 4 of the microbiological analysis of the wells in the village of Matões dos Moreiras, in the municipality of Codó-MA, and according to the criteria established by Ordinance GM/MS No. 888/2021, which regulates the standards of potability of water for human consumption in Brazil, it is possible to state that none of the samples analyzed meets the microbiological requirements for potability.

Table 4. Result of microbiological analyses of the water from the wells.

WELL	VMP*	Total Coliforms	*E. coli*
Bucket	Absence in 100 mL	Presence	Presence
Artesian		Presence	Absence
Cacimbão		Presence	Presence

*MPV: Maximum amount allowed.
Source: The authors (2025)

According to current legislation, the reference parameter for total coliforms and *Escherichia coli* (*E. coli*) in water intended for human consumption is the absence of a sample in 100 mL. The presence of these bacteria is considered indicative of recent fecal contamination or failures in the protection and treatment of the water source, which represents a direct risk to public health.

In the case of **the cacimba**, the presence of total coliforms and *E. coli* was observed, indicating significant microbiological contamination. This condition may be related to proximity to sources of anthropogenic pollution, the presence of wild animals, domesticated animals and small animals such as birds, goats and pigs used in family subsistence. The **cacimbão** presented a similar profile, with simultaneous presence of total coliforms and *E. coli*, reinforcing the microbiological inadequacy of this source of supply.

The **artesian well**, although it showed absence of *E. coli*, still registered the presence of total coliforms, which is also incompatible with the established potability standards. This result suggests **non-fecal environmental contamination or the presence of natural heterotrophic bacteria**, which still require corrective actions, such as disinfection and protection of the well structure.

The presence of *E. coli* in two of the three sources analyzed constitutes a **serious health violation**, since this bacterium is a specific marker of recent fecal contamination and may be associated with the presence of pathogens such as viruses, protozoa, and enteric bacteria. The consumption of these waters, without adequate treatment, represents a high risk of waterborne diseases, such as gastroenteritis, viral hepatitis, and intestinal infections (Vila Nova and Tenório, 2019; Oliveira et al., 2020).

SENSORY CHARACTERIZATION OF WELL WATERS

Table 5 shows the results referring to the mean odor analysis of the water from the wells of the village of Matões dos Moreiras in Codó-MA, where values of odor intensity were assigned by each analyst.

Table 5. Sensory panel of odor of the waters of the wells.

Samples	I	II	III	IV	VMP	Characteristic	Average
Bucket	0	4	0	0	6	1	1
Artesian	2	10	2	0	6	1,3	3,5
Cacimbão	8	12	4	2	6	1,3,4	**6,5**

Source: The authors (2025)

Taste analysis was not carried out due to the microbiological characteristic of the analyzed waters, and, according to the methodology, samples that pose a health risk should not be tasted. As the parameters of odor and taste are related, if a sample presents intensity above the VMP for odor, then the intensity of the taste will also be outside the maximum allowed value (APHA, 2005).

Regarding the intensity of the odor in the three samples analyzed, the bucket well presented an average of 6.5, which is above the Maximum Allowed Value (MPV) established for potability. Among the odors identified, those described as earth/mold, grass, and swampy/sulfurous odorous stood out, in this order of prevalence. The first two characteristics may be associated with the rudimentary structure of the well and its geographical location. Because it is a well without a seal around the edge and located in an area of steep relief and dense vegetation, it is likely that, during precipitation events, surface runoff of leaves, sticks and other organic materials into the well will occur. According to Domingues et al. (2020), the presence of undesirable odors in water may be associated with the occurrence of organic compounds, chemical substances, or contaminants of microbiological origin, which, as highlighted by Silva et al. (2020), represents a relevant indicator of possible contamination or degradation of water quality.

The swampy/sulfurous odor, in turn, may be related to the presence of sulfur compounds, such as hydrogen sulfide, from the decomposition of organic matter transported by rainwater. In addition, the presence of iron and manganese in concentrations above the allowed limits contributes significantly to the manifestation of unpleasant odors, corroborating the data obtained in the physicochemical analysis of the sample.

CONCLUSION

The integrated characterization of groundwater consumed in the village of Matões dos Moreiras, in Codó-MA, shows that, in addition to non-conformities with the standards established by Brazilian legislation, there is a worrying scenario of sanitary vulnerability and lack of systematic control of water quality.

The simultaneity of physicochemical nonconformities, the presence of microbiological contaminants and sensory alterations, especially in the wells of the cacimba and cacimbão types, suggests not only punctual contamination, but a structural pattern of exposure to water risks.

The case of the artesian well, although with better microbiological performance, reveals a high load of minerals and dissolved solids, pointing to potential geochemical and anthropogenic impacts. This scenario reinforces the urgency of implementing intersectoral actions that integrate health education, community water management, regular monitoring, and investments in disinfection technologies appropriate to the rural reality. In addition, the need to deepen regional studies on underground geodynamics and the interface between land use and occupation and water quality is highlighted, in order to subsidize evidence-based public policies and promote environmental justice in access to drinking water.

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REFERENCES

1. Alkarkhi, A. F. M., Ahmad, A., Ismail, N., & Easa, A. M. (2008). Multivariate analysis of heavy metals concentrations in river estuary. *Environmental Monitoring and Assessment, 143*(1–3), 179–186. https://doi.org/10.1007/s10661-007-9966-x

2. Alves, S. G. S., Ataide, C. D. G., & Silva, J. X. (2018). Microbiological analysis of total and thermotolerant coliforms in water from drinking fountains in a public park in Brasília, Federal District. *Revista Científica Sena Aires, 7*(1), 12–17. https://rdcsa.emnuvens.com.br/revista/article/view/733/1154

3. American Public Health Association, American Water Works Association, & Water Environment Federation. (2005). *Standard methods for the examination of water and wastewater* (21st ed.). American Public Health Association.

4. Ayach, L. R., Pinto, A. L., Cappi, N., & Guimarães, S. T. de L. (2009). Contamination of groundwater by coliforms: A study of the city of Anastácio-MS. *Climatologia e Estudos da Paisagem, 4*(1), 5–26. https://www.periodicos.rc.biblioteca.unesp.br/index.php/climatologia/article/download/3268/2743/14359

5. Bezerra, A. D. A., Rocha, J. C. da, Nogueira, E. R., Sousa, D. M. L. de, Araújo, F. G. D. M., Brandão, M. G. A., & Pantoja, L. D. M. (2018). Situational analysis of groundwater quality from wells in the metropolitan region of Fortaleza, Ceará State, Brazil. *Acta Biomédica Brasiliensia, 9*(1), Article 158. https://doi.org/10.18571/acbm.158

6. Brazil. Ministry of Health. (2017). *Consolidation Ordinance No. 5, of September 28, 2017. Consolidation of the rules on the health actions and services of the Unified Health System*. Diário Oficial da União. https://www.gov.br/saude/pt-br/assuntos/saude-de-a-a-z/s/saude-da-pessoa-com-deficiencia/legislacao/portaria-de-consolidacao-no-05-de-28-de-setembro-de-2017.pdf/view

7. Brazil. Ministry of Health. (2021). *Ordinance No. 888, of May 4, 2021. Annex XX. Establishes the procedures for the control and surveillance of the quality of water for human consumption and its potable drinking standard*. Diário Oficial da União, (85, Section 1), 127. https://www.in.gov.br/en/web/dou/-/portaria-gm/ms-n-888-de-4-de-maio-de-2021-318461562

8. CETESB, & ANA. (2011). *National guide for sample collection and preservation: Water, sediment, aquatic communities, and liquid effluents* (C. J. Brandão, Ed.). CETESB; ANA. https://cetesb.sp.gov.br/wp-content/uploads/2021/10/Guia-nacional-de-coleta-e-preservacao-de-amostras-2012.pdf

9. Coelho, S. C., Duarte, A. N., Amaral, L. S., Santos, P. M., Salles, M. J., Santos, J. A. A., & Sotero-Martins, A. (2017). Monitoring of well water as a health assessment strategy in a rural community in the city of São Luís, MA, Brazil. *Ambiente & Água, 12*(1), 156–167. https://doi.org/10.4136/ambi-agua.1962

10. Costa, R. N., Suda, C. N. K., & Pinto, F. A. (2024). Water analysis as prevention for the occurrence of waterborne diseases: An integrative review. *Technical Journal of Environmental Sciences, 1*(8), Article 128. https://ipabhi.org/repositorio/index.php/rca/article/view/128

11. Domingues, L. F., Cruz, G. Q. N., Castro, I. P. de, Archioli, I. A., Lopes, L. C., & Oliveira, M. R. M. de. (2021). Production of charcoal from orange peel activated with calcium chloride ($CaCl_2$) and its application in the treatment of water contaminated with nitrate (NO_3^-). *Brazilian Journal of Development, 7*(1), 404–413. https://doi.org/10.34117/bjdv7n1-030

12. Ferreira Filho, S. S., & Alves, R. (2006). Techniques for evaluating taste and odor in water supply: Analytical method, sensory analysis, and consumer perception. *Engenharia Sanitária e Ambiental, 11*(4), 362–370. https://doi.org/10.1590/S1413-41522006000400009

13. France, A. C., Abreu, G. P. de, Balioni, L. F., Capellato, P., Ranieri, M. G. A., Fonseca, A. L., Ribeiro, G. C., Marques, P. S., & Sachs, D. (2021). Microbiological analysis of the water provided to a Health Unit in the Municipality of Itajubá, Minas Gerais. *Research, Society and Development, 10*(6), Article e33910615220. https://doi.org/10.33448/rsd-v10i6.15220

14. Google Maps. (2025). *Codó Maranhão* [Satellite image]. https://www.google.com/maps/place/Cod%C3%B3,+MA,+65400-000/@-4.5210813,-43.9585158,11z/data=!4m6!3m5!1s0x78bf16cf1e200a1:0x41ecdc5fb99aae3!8m2!3d-4.4535444!4d-43.8877885!16zL20vMGZmaGh0?entry=ttu&g_ep=EgoyMDI1MDMxOS4yIKXMDSoJLDEwMjExNDUzSAFQAw%3D%3D

15. Lira, R. da S., & Gonçalves, M. F. (2022). Identification of the type of supply and monitoring of the quality of water for human consumption in the municipality of Coelho Neto, Maranhão. *Research, Society and Development, 11*(4), Article e27711421771. https://doi.org/10.33448/rsd-v11i4.21771

16. Macedo, I. M. E., Lima, F. R. F., Lima, G. M. de S. S., Oliveira, F. H. P. C., Cunha Filho, M., & Shinohara, N. K. S. (2021). Microbiological analysis of drinking water in food services in municipalities of Pernambuco (Northeast Brazil). *Brazilian Journal of Development, 7*(11), 103530–103542. https://doi.org/10.34117/bjdv7n11-124

17. Müller, A. L. de C., Severo, L. G. R., Souza, B. S. de, Bueno, C. G., Osório, D. M. M., & Berlese, D. B. (2022). Physicochemical and microbiological analysis of groundwater in a municipality in the southern region of Brazil. *Águas Subterrâneas, 36*(2), Article 30182. https://doi.org/10.14295/ras.v36i2.30182

18. Oliveira, F. C. de, Röhnelt, N. M. S., Ritzel, R. G. F., Heck, T. M. da S., & Staggemeier, R. (2020). Enteric viruses: Main waterborne pathologies and their clinical manifestations. *Revista Conhecimento Online, 1*, 191–217. https://doi.org/10.25112/rco.v1i0.1598

19. Oliveira, R. M. M., Oliveira, L. R. M., & Zaidan, G. S. de A. (2025). Trophic state index and quality of surface and groundwater used in rural supply in Maranhão. *Cuadernos de Educación y Desarrollo, 17*(1), Article e7392. https://doi.org/10.55905/cuadv17n1-160

20. Oliveira Junior, M. A., Silva, N. C. S., & Prado, M. F. (2023). Quality of water consumed in drinking fountains at IFTM – Uberlândia Campus. *Environment and Sustainability Journal, 12*(25), 3–16. https://doi.org/10.22292/mas.v12i25.1115

21. Paiva, R. F. P. S., & Souza, M. F. P. (2018). Association between socioeconomic, sanitary, and primary care conditions and hospital morbidity due to waterborne diseases in Brazil. *Cadernos de Saúde Pública, 34*(1), Article e00017316. https://doi.org/10.1590/0102-311X00017316

22. Peil, G. H. S., Kuss, A. V., & Gonçalves, M. C. F. (2015). Evaluation of the bacteriological quality of water used for public supply in the municipality of Pelotas - RS - Brazil. *Ciência e Natura, 37*(1), 79–84. https://doi.org/10.5902/2179460X14941

23. Ramoutar, S. (2020). The use of Colilert-18, Colilert, and Enterolert for the detection of faecal coliform, *Escherichia coli*, and Enterococci in tropical marine waters, Trinidad and Tobago. *Regional Studies in Marine Science, 40*, Article 101490. https://doi.org/10.1016/j.rsma.2020.101490

24. Rutkowski, E. W., Lessa, S. N., & Oliveira, E. G. de. (1999). Brazilian development x environment: Trajectory of water problematization. *Revista de Ciência & Tecnologia, 7*(14), 23–30. https://www.academia.edu/7112806/Desenvolvimento_Brasileiro_X_Meio_Ambiente_Trajet%C3%B3ria_da_Problematiza%C3%A7%C3%A3o_da_%C3%81gua_Brazilian_Development_X_Environmental_Issues_Water_Problematization_Trajectory

25. Santos, J. A. R., Nascimento, R. S., Siqueira, E. V. S., Silva Filho, J. R. V., Santos, K. E., Santos, A. S., Santos, M. I., Moreira, J. J. S., Siqueira, C. G., & Fraga, L. E. (2024). Relationship between the concentration of free residual chlorine and the presence of microorganisms in the water of artesian wells intended for human consumption. *Scientia Plena, 20*(8), Article 089904. https://doi.org/10.14808/sci.plena.2024.089904

26. Silva, A. L. O., Ramos, M. S., Luiz, M. R., Souza, N. C., Nascimento, A. P. S., Amorim Silva, J. E. O., Ramos, E. F., & Amorim, F. V. (2020). Possible effects of aluminum on treated water. *Brazilian Journal of Development, 6*(1), 1413–1420. https://doi.org/10.34117/bjdv6n1-098

27. Soares, A. C. G. M., Silva, R. A. S., Jesus, C. V. F., Santana, R. F., Lima, Á. S., Lima, S. O., & Marques, M. N. (2020). Water and health risk assessment in the Aracaju Expansion Zone - SE. *Ambiente & Sociedade, 23*, Article e02561. https://doi.org/10.1590/1809-4422asoc20170256r1vu2020L4AO

28. Sousa, S. S., Silva, W. S., Miranda, J. A. L., & Rocha, J. A. (2016). Physicochemical and microbiological analysis of the water of the Grajaú River, in the city of Grajaú – MA. *Ciência e Natura, 38*(3), 1615–1625. https://doi.org/10.5902/2179460X23341

29. Sperling, M. V. (2007). *Studies and modeling of river water quality: Principles of biological treatment of wastewater* (Vol. 7). Departamento de Engenharia Sanitária e Ambiental, Universidade Federal de Minas Gerais.

30. Vila Nova, F. V. P., & Tenório, N. B. (2019). Waterborne diseases associated with the degradation of water resources, municipality of Caruaru - PE. *Caminhos de Geografia, 20*(71), 250–264. https://doi.org/10.14393/RCG207145545