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# POTABILITY OF RAINWATER IN THE EASTERN AMAZON

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## ABSTRACT

**Objective:** This study aimed to assess the feasibility of using rainwater for human consumption as an alternative water supply in the Eastern Amazon, through a social technology for collection and treatment.

**Theoretical Framework:** Despite the region's water abundance, access to potable water is limited, especially in isolated communities. Rainwater harvesting emerges as a viable alternative, provided its quality is rigorously evaluated.

**Method:** The research was conducted in seven households on Ilha das Onças (Barcarena-PA) and one control unit in Belém. Water samples collected from rooftops and stored in cisterns were analyzed before and after treatment with sodium hypochlorite and filtration using activated carbon and polypropylene candles. Physical-chemical parameters (pH and electrical conductivity) were evaluated and compared with commercial brands, while microbiological parameters (coliforms) and trace metals were also analyzed.

**Results and Discussion:** Rainwater had an average pH of 5.16 and conductivity of 9.1 $\mu S \cdot cm^{-1}$; after treatment, these values slightly increased but remained below those found in commercial waters. Treatment reduced the microbiological load, although 53.8% of samples still showed total coliforms and 20.5% *E. coli*. In general, the samples did not show metal concentrations above the levels established by legislation.

**Research Implications:** The results suggest that, with proper operation and maintenance, rainwater harvesting and treatment systems are a viable solution for water supply in Amazonian communities.

**Originality/Value:** The study highlights a low-cost, sustainable alternative adapted to the region's socio-environmental context for promoting health and well-being.

**Keywords:** Rainwater, Potability, Amazon, Social Technology.

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## POTABILIDADE DA ÁGUA DE CHUVA NA AMAZÔNIA ORIENTAL

**RESUMO**

**Objetivo:** Este estudo teve como objetivo avaliar a viabilidade do uso da água de chuva para consumo humano como alternativa de abastecimento na Amazônia Oriental, por meio de uma tecnologia social de captação e tratamento.

**Referencial Teórico:** Apesar da abundância hídrica da região, o acesso à água potável é limitado, especialmente em comunidades isoladas. A captação de água de chuva desponta como alternativa viável, desde que sua qualidade seja rigorosamente avaliada.

**Método:** A pesquisa foi conduzida em sete residências na Ilha das Onças (Barcarena-PA) e uma unidade controle em Belém. Foram analisadas amostras de água coletadas em telhados e armazenadas em cisternas, antes e após tratamento com hipoclorito de sódio e filtragem com vela de carvão ativado e polipropileno. Avaliaram-se parâmetros físico-químicos (pH e condutividade elétrica), os quais foram comparados com marcas comerciais, além de parâmetros microbiológicos (coliformes) e metais traço.

**Resultados e Discussão:** A água de chuva apresentou pH médio de 5,16 e condutividade de 9,1 $\mu S \cdot cm^{-1}$; após o tratamento, esses valores aumentaram levemente, mantendo-se abaixo dos observados nas águas comerciais. O tratamento reduziu a carga microbiológica, embora 53,8% das amostras ainda apresentassem coliformes totais e 20,5%, *E. coli*. As amostras, em geral, não apresentaram metais em níveis acima do preconizado pela legislação.

**Implicações da Pesquisa:** Os resultados sugerem que, com operação e manutenção adequadas, sistemas de aproveitamento de água de chuva são uma solução viável para o abastecimento em comunidades amazônicas.

**Originalidade/Valor:** A pesquisa destaca uma alternativa de baixo custo, sustentável e adaptada ao contexto socioambiental da região para a promoção de saúde e bem-estar.

**Palavras-chave:** Água de Chuva, Potabilidade, Amazônia, Tecnologia Social.

## POTABILIDAD DEL AGUA DE LLUVIA EN LA AMAZONÍA ORIENTAL

**RESUMEN**

**Objetivo:** Este estudio tuvo como objetivo evaluar la viabilidad del uso del agua de lluvia para el consumo humano como una alternativa de abastecimiento en la Amazonía Oriental, mediante una tecnología social de captación y tratamiento.

**Marco Teórico:** A pesar de la abundancia hídrica de la región, el acceso al agua potable es limitado, especialmente en comunidades aisladas. La captación de agua de lluvia surge como una alternativa viable, siempre que se evalúe rigurosamente su calidad.

**Método:** La investigación se llevó a cabo en siete viviendas en la Isla de las Onças (Barcarena-PA) y una unidad de control en Belém. Se analizaron muestras de agua recolectadas en techos y almacenadas en cisternas, antes y después del tratamiento con hipoclorito de sodio y filtración con vela de carbón activado y polipropileno. Se evaluaron parámetros fisicoquímicos (pH y conductividad eléctrica), los cuales se compararon con marcas comerciales, además de analizarse parámetros microbiológicos (coliformes) y metales traza.

**Resultados y Discusión:** El agua de lluvia presentó un pH medio de 5,16 y una conductividad de 9,1 $\mu S \cdot cm^{-1}$; después del tratamiento, estos valores aumentaron ligeramente, manteniéndose por debajo de los observados en aguas comerciales. El tratamiento redujo la carga microbiológica, aunque el 53,8% de las muestras aún presentó coliformes totales y el 20,5% *E. coli*. En general, las muestras no presentaron concentraciones de metales por encima de los niveles establecidos por la legislación.

**Implicaciones de la investigación:** Los resultados sugieren que, con una operación y mantenimiento adecuados, los sistemas de captación y tratamiento de agua de lluvia son una solución viable para el abastecimiento en comunidades amazónicas.

**Originalidad/Valor:** La investigación destaca una alternativa de bajo costo, sostenible y adaptada al contexto socioambiental de la región para promover la salud y el bienestar.

**Palabras clave:** Agua de Lluvia, Potabilidad, Amazonía, Tecnología Social.



## 1 INTRODUCTION

Ensuring the availability and sustainable management of drinking water is a fundamental objective for the United Nations (UN, 2015), considering its importance for the maintenance of life and for human development. However, effective measures to ensure this right have never been clearly defined, and approximately 25% of the world's population still does not have regular access to drinking water (WHO, 2022). The Amazon region exemplifies this scenario. Although it is one of the largest holders of fresh water on the planet, much of its population faces difficulties in obtaining drinking water and the availability of basic sanitation services.

Scattered occupations in rural areas of the Amazon, associated with difficult access and lack of electricity, aggravate the lack or inadequacy of sanitation services (Araújo & Neu, 2024). According to Silvério *et al*. (2024), the scarcity of drinking water has a significant impact on food insecurity, and this relationship is more pronounced in the North and Northeast of Brazil. Studies by Basta (2024) indicate that the lack of access to safe water has increased the incidence of the triad composed of diarrhoea, dehydration and malnutrition in indigenous communities, such as the Yanomami Indigenous Land. In addition, inadequate provision of services and distribution of contaminated water contribute to the incidence of diarrheal diseases, especially in vulnerable communities (Costa *et al.*, 2021). Alternative systems represent a viable strategy for the universalisation of sanitation. Rainwater harvesting and use is an ancient technology, with historical records dating from 850 BC in the region that currently corresponds to Jordan (Sacadura, 2011). In Brazil, the use of tanks began in 1949, with the implementation of the first systems on the island of Fernando de Noronha (May, 2004). In 2003, the "One Million Cisterns Programme" was launched, the largest and most successful social technology initiative in the country, which transformed the dynamics of living with drought and promoted water security (Dias, 2013).

In the Amazon, the use of rainwater is still incipient, mainly due to the abundance of surface water resources in the region. The first rainwater harvesting and storage systems in the state of Pará were implemented in 2004, through the project "Clean Water is Life" (Mendes & Veloso, 2014). Faced with challenges such as lack of infrastructure, irregular distribution and *low quality of available water, other initiatives aimed at capturing and storing rainwater have been implemented in the Amazon, as reported by Andrade (2009), Veloso et al*. (2012) and Neu *et al*. (2018). However, these actions are still insufficient to solve the shortage of drinking water in the region, given the territorial extension, population dispersion and logistical challenges involved. According to Júnior (2018), rainwater harvesting systems are a viable alternative, as they offer water in adequate quantity and quality, in addition to presenting good cost-benefit. Thus, the efficient implementation of these systems would contribute to the mitigation of the water deficit in the Amazon, reinforcing the need for comprehensive public policies and continuous investments in the sector.

It is important to emphasise that the quality of rainwater is influenced by a number of factors, especially the impact of human activities. The use of this water for human consumption requires, therefore, the realisation of detailed studies that evaluate its qualitative characteristics. Moreira *et al*. (2012), in a research conducted in the municipality of Lucas do Rio Verde (MT), identified the presence of pesticides in 56% of the collected rainwater samples. Similarly, regions subject to the influence of industrial activities, as highlighted by Ying (2004), may also have contaminated water, making them unfit for human consumption.

Therefore, the present study aimed to evaluate the quality of rainwater collected by systems installed in rural and urban areas in the state of Pará. Physicochemical, biological and metal analyses were performed over eight months, in order to verify the viability of rainwater as a safe alternative for human consumption in the Eastern Amazon.

## 2 METHODOLOGY

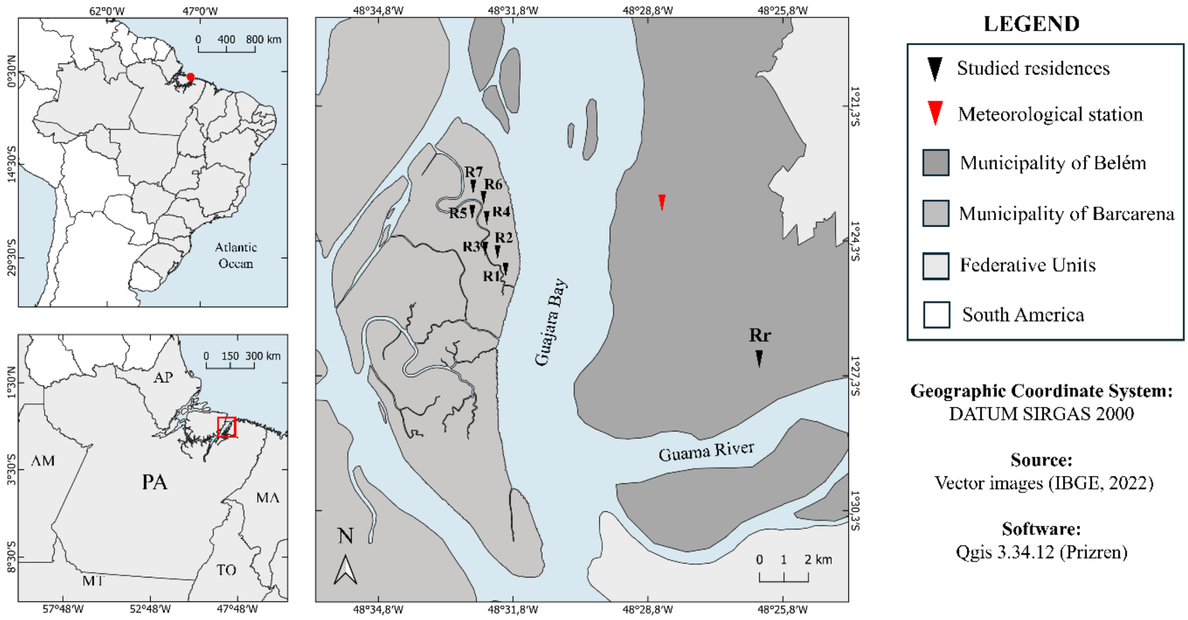
### 2.1 STUDY AREA

The study was conducted in rural and urban areas in the state of Pará (Figure 1). In the rural region, seven rainwater harvesting systems were monitored (Figure 2), implemented in residences of the Furo Grande riverside community (R1, R2, R3...), located on Ilha das Onças, municipality of Barcarena. Additionally, a system controlled by the research team was monitored in an urban area, specifically in a condominium in the municipality of Belém (Rr).

Both residences located in the rural area and those located in the urban area do not have access to the water supply service provided by the government.

**Figure 1**

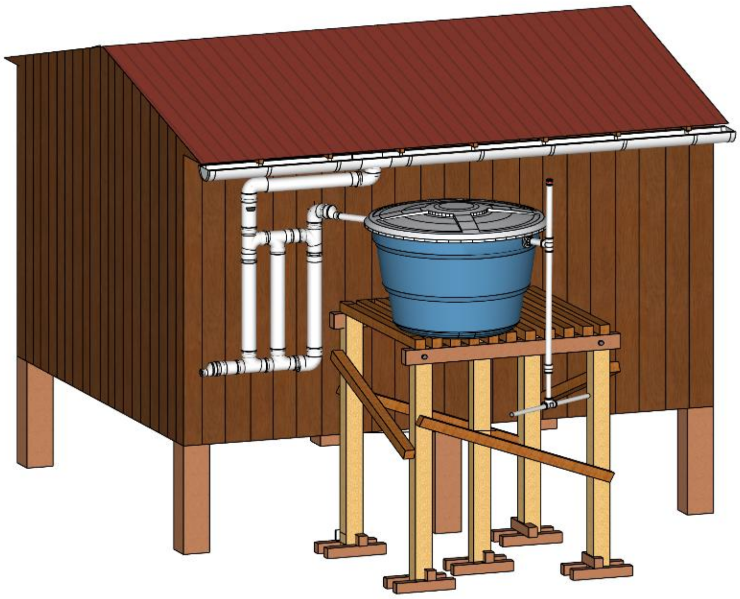
*Location map of the study area.*




Ilha das Onças is part of the Agroextractivist Settlement Project (PAE) Ilha da Onças, created in November 2005. Located in the Guajarino Estuary, on the left bank of Guajará Bay (Figure 1), the island is drained by boreholes and streams. Along the Furo Grande there are, in a dispersed way, extractive families. The PAE Ilha das Onças, covers an area of approximately 8 thousand hectares and has 907 settled families (INCRA, 2025). Only 1.6% of households are served with rainwater supply systems, while the others depend on the water supply through a tanker, which distributes weekly 40 litres of water per family, bottled without potability control. The lack of access to drinking water exposes this community to conditions of extreme vulnerability, water insecurity and health risks. On the other hand, the residential condominium located in an urban area, in the Curió-Utinga neighbourhood, bordering the Utinga State Park (PEUt), has access to drinking water through the autonomous initiative of the residents themselves, who have cost the drilling of a artesian well, as well as the treatment and distribution of water.

**Figure 2**

*Model of Rainwater Harvesting Systems implemented in homes.*

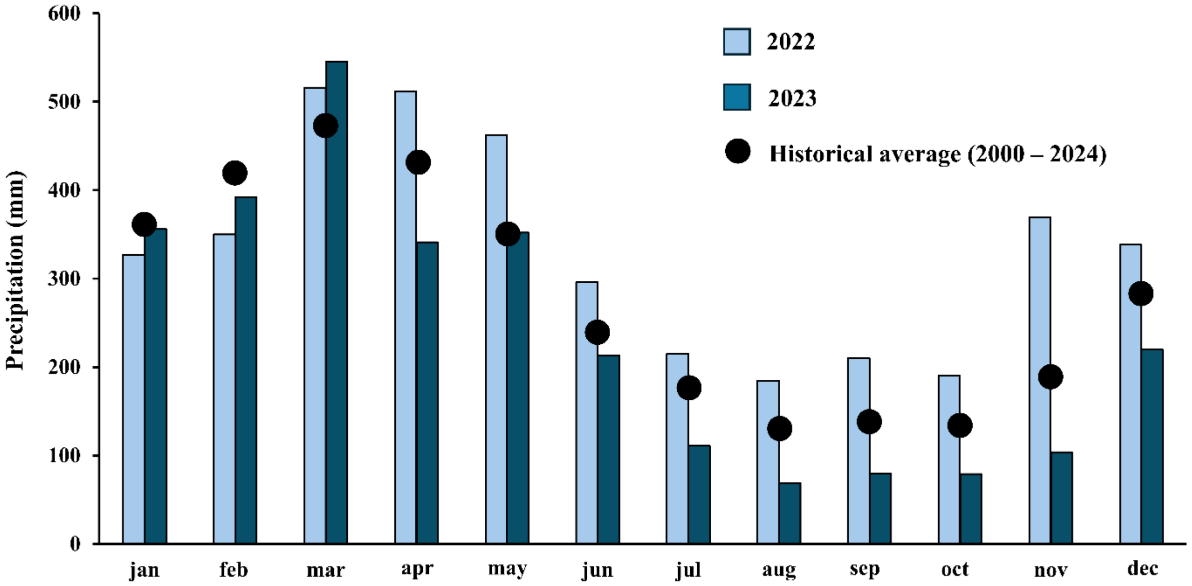


## 2.2 CLIMATE CHARACTERISATION

The region under study has high rainfall, with average annual rainfall of 3112.5 ± 319.2 mm (INMET, 2025). The climate is of the "Af" type, humid equatorial, characterised by high humidity and a marked rainfall seasonality. During the rainiest period, between January and May, the monthly averages reach 356.4 ± 37.1 mm, while in the less rainy period, from August to November, the monthly averages are 162.2 ± 36.2 mm (Figure 3), referring to the series from 2000 to 2024 (INMET, 2025). During the rainiest season, it is common to record the occurrence of daily rainfall greater than 100 mm, positioning Belém among the cities with the highest rainfall volume in Brazil. This climatic condition gives the region a high potential for the supply of water intended for human consumption, through the capture of rainwater (IBGE, 2020).

**Figure 3**

*Average monthly precipitation in Belém according to the series from 2000 to 2024.*




## 2.3 SAMPLING AND ANALYTICAL METHODS

The monitoring of rainwater quality was conducted through the analysis of natural water samples and after treatment, during the period from October 2022 to June 2023, totalling nine collection campaigns. The untreated natural water samples were collected directly from the fibreglass reservoirs used for rainwater storage. The post-treatment samples were collected directly at the filter outlet. The treatment of water for human consumption is carried out by the local community, according to a protocol that includes the addition of 2.5% hypochlorite in a plastic bucket (2 drops per litre of water), manual agitation, rest for 30 minutes and subsequent filtration. Filtration was performed by means of handmade filters, made with plastic buckets and filter candle composed of polypropylene and activated carbon. The micro porosity of the candles allows the retention of particles, while the activated carbon eliminates excess chlorine, ensuring the removal of unpleasant taste or odour from the water.

For all samplings, physical-chemical parameters, such as temperature and pH, were determined *in situ*, using a portable Thermo Orion 4-star parameter, while the electrical conductivity of water was measured using a portable conductivity metre Amber Science - model 2052. Samples for microbiological analysis were collected in only six of the campaigns undertaken, following the methodology of COLItest®, in which the indicator paper was inserted into 100 mL of water sample, collected with the aid of a graduated and sterilised becker. The samples were kept in a refrigerated thermal box during transport in the field until the time of incubation. The incubation was carried out in an incubator (B.O.D SL model 200/364) for a period of 15 hours, at a constant temperature of 36 °C, with subsequent counting of *E. coli* and total coliforms. The presence of faecal coliforms was indicated by blue points on the cartouche, while pink points indicated the presence of non-faecal coliforms. After counting, the number of points was multiplied by a correction factor (x80), as specified by the manufacturer, to obtain the value expressed in colony-forming units in 100 mL of water (CFU/100 mL).

For the determination of the concentration of trace metals aluminium (Al), arsenic (As), barium (Ba), cobalt (Co), cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), mercury (Hg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), and selenium (Se), titanium (Ti), uranium (U), vanadium (V), and zinc (Zn), the samples were collected, stored in falcon tubes (50 mL) and preserved with 50.0 µL of nitric acid ($HNO_3$). The determination of metal concentrations was performed by inductively coupled plasma mass spectrometry (ICP-MS), using an Agilent equipment, model 7900. The analyses were carried out at the Environmental Chemistry and Health Laboratory, linked to the Environment Section of the Evandro Chagas Institute.

For the evaluation of water potability, all parameters analysed were compared to the standards established by the Consolidation Ordinance GM/MS n. 888 (2021) of the Ministry of Health, with the exception of electrical conductivity, whose reference values were based on the guidelines established by the Environmental Company of the State of São Paulo (CETESB, 2014).

## 2.4 ANALYSIS OF WATER MARKETED IN THE STATE OF PARÁ

For comparison with the values of pH and electrical conductivity measured in samples of rainwater collected and treated in homes in rural and urban areas, held the measurement of these parameters in bottled water marketed in the state of Pará. For this, four to eight bottles of water were purchased, with a capacity varying between 300 and 500 ml, from eight brands widely marketed in eight municipalities of Pará. The samples were analysed in the laboratory, following the same methodology applied for the analysis of pH and electrical conductivity of rainwater.

## 3 RESULTSS AND DISCUSSÕES

### 3.1 PH AND ELECTRICAL CONDUCTIVITY

The mean pH value of the untreated natural rainwater collected directly from the cistern was 5.16 ± 0.45 and did not present statistically significant differences between households (*p-value* = 0.322). After treatment, which consisted of the addition of sodium hypochlorite and filtration, the mean value increased to 5.76 ± 0.59 (Table 1), with a statistically higher value of Rr in relation to the others (*p-value* = 0.048).

**Table 1**

*pH of water in the studied residences*

| | Untreated | | | Post-treatment | | |
|---|---|---|---|---|---|---|
| Residences | Minimum | Maximus | Mean ± SD | Minimum | Maximus | Mean ± SD |
| R1 | 4.37 | 5.78 | 5,15 ± 0,51 | 4.66 | 6.20 | 5.56 ± 0.53 |
| R2 | 4.29 | 5.48 | 5,00 ± 0,52 | 5.67 | 6.37 | 5.93 ± 0.31 |
| R3 | 4.23 | 5.66 | 5,11 ± 0,44 | 5.45 | 6.11 | 5,75 ± 0,26 |
| R4 | 4.65 | 5.68 | 5,09 ± 0,37 | 4.87 | 6.27 | 5.62 ± 0.51 |
| R5 | 5.22 | 5.70 | 5.43 ± 0.17 | 5.05 | 6.21 | 5.60 ± 0.41 |
| R6 | 4.15 | 5.59 | 4,83 ± 0,40 | 4.31 | 7.67 | 5.55 ± 0.97 |
| R7 | 4.84 | 5.68 | 5,28 ± 0,34 | 5.44 | 6.06 | 6.38 ± 0.30 |
| Rr | 4.59 | 5.95 | 5,32 ± 0,48 | 5.75 | 6.73 | 6.36 ± 0.31 |
| **Overall Mean ± SD** | **5,16 ± 0,45** | | | **5,76 ± 0,59** | | |

The theoretical pH of rainwater is 5.60, due to the ionisation of a weak acid, which releases hydrogen ions leaving the pH slightly acidic, even in natural regions with low human intervention (Baird & Cann, 2011). The slight acidity of rainwater is attributed to the balance established between water and $CO_2$ concentration in the atmosphere (Cunha *et al.*, 2009). Marques *et al.* (2011) observed a mean pH value of 5.63 ± 0.51 in Cuiabá. Stradioto (2004), in a study carried out in the region of the city of Rio Claro (SP), found a pH value of 5.90. Cerqueira *et al*. (2014) measured an average pH of 5.77 in the city of Juiz de Fora (MG), that is, all showed higher means than that observed in this study. In the Amazon, Brinkman and Santos (1973); Stallard and Edmond (1981); Neu (2009) and Andreae and Crutzen (1997) found pH values ranging from 4.20 to 5.67. According to Andreae and Crutzen (1997), in tropical and equatorial regions, natural sources of organic acids can contribute to more acidic pH values of rainwater. Neu (2009) observed more acidic values associated with *the first rains after a drier period, which wash the atmosphere and Marques et al.* (2011) point out that acidity can be influenced by multiple factors, including local geology, vegetation, soil type, sea influence and human actions.

The electrical conductivity of the natural water of the reservoirs, without treatment, presented average values of 9.1 ± 3.9 μS.cm$^{-1}$, without statistically significant differences between the residences (*p-value* = 0.410). After treatment, the mean value increased to 25.9 ± 15.4 μ.cm$^{-1}$ (Table 2), with a statistically significant difference between Rr and the others (*p-value* = 0.008). As in the pH analyses, all households showed a statistically significant increase in the electrical conductivity of water after the filtration and treatment process.

**Table 2**

*Electrical conductivity (μS.cm$^{-1}$) of water in monitored households.*

| | Untreated | | | Post-treatment | | |
|---|---|---|---|---|---|---|
| Residences | Minimum | Maximus | Mean ± SD | Minimum | Maximus | Mean ± SD |
| R1 | 5.8 | 18.1 | 11.5 ± 4.0 | 12.5 | 27.0 | 22.2 ± 6.3 |
| R2 | 6.4 | 13.8 | 9.6 ± 3.1 | 14.4 | 23.3 | 17.8 ± 3.9 |
| R3 | 6.0 | 14.0 | 9.1 ± 3.2 | 20.3 | 35.9 | 26.1 ± 5.0 |
| R4 | 4.2 | 12.5 | 7.1 ± 2.6 | 15.9 | 35.3 | 27.3 ± 6.7 |
| R5 | 6.2 | 15.0 | 9.0 ± 3.1 | 6.6 | 28.4 | 16.1 ± 8.5 |
| R6 | 6.3 | 19.0 | 10.3 ± 4.3 | 10.0 | 90.8 | 33.7 ± 28.3 |
| R7 | 5.0 | 10.8 | 7.3 ± 2.2 | 5.8 | 20.6 | 10.8 ± 5.8 |
| Rr | 5.7 | 20.0 | 8.7 ± 4.9 | 20.0 | 52.5 | 41.5 ± 10.1 |
| **Overall Mean ± SD** | **9.1 ± 3.9** | | | **25,9 ± 15,4** | | |

The statistical difference of Rr, compared to the others, in relation to the values of electrical conductivity and pH after treatment, can be attributed to the more regular use of hypochlorite, as recommended by the water treatment protocol. However, this result may also be associated with the fact that, in the reference residence, the treatment system was not used in a recurring and daily way, unlike the systems implanted in Ilha das Onças. The continuous use of the filtration candle and the percolation of water through its structure can lead to the leaching of ions and elements that contribute to the increase of the electrical conductivity and the pH of the treated water. These ions become less abundant in the filtration sails of the riverside residences, which are used more frequently.

According to Neu (2009), rainwater is poor in ions, resulting in low values of electrical conductivity. In a study carried out in the Upper Xingu Basin (MT), low conductivity values ranging from 4.2 μS.cm$^{-1}$ during the rainiest period to 32.9 μS.cm-1 were also observed in the first rainfall events after dry months. Marques *et al.* (2011), in Cuiabá, found values ranging from 7.25 ± 5.25 μS.cm$^{-1}$. The electrical conductivity is an important parameter for monitoring the composition of water quality, since it can indicate changes in the composition of water bodies.

However, it is a parameter that does not specify the quantity or type of component present (Boesch, 2002; Esteves, 2011). Despite this limitation, its importance is recognised in the control and determination of water quality status (Di Blasi *et al.*, 2013).

The pH results were compared with Ordinance GM/MS n. 888 (2021) of the Ministry of Health, which defines a range of 6.00 to 9.50 as suitable for human consumption water. After treatment of rainwater (Tables 1 and 2), pH and electrical conductivity values showed significant changes in all households after treatment. For pH, the reduction of acidity was a positive point; while the increase in electrical conductivity did not exceed the acceptable limit (100 µS.cm$^{-1}$), established by CETESB for non-impacted environments. It is noteworthy that there is no standard of electrical conductivity established in the legislation for potability, however, according to Von Sperling (2014), natural waters have values in the range of 10 to 100 µS.cm$^{-1}$. Water polluted by industrial sewage can reach values of 1000 µS.cm$^{-1}$. The low concentration of ions in rainwater is an indicator of water not impacted by human activities (Neu *et al.*, 2018).

Rain water, properly treated, is a source of water with better physicochemical characteristics compared to the commercial options analysed. In this study, we observed that the average pH of the treated rainwater was 5.76 ± 0.59, indicating a slight acidity, while the average pH value of the certified and marketed waters in the State of Pará was 4.65 ± 0.33 (Table 3). The rainwater submitted to the treatment presented a concentration of $H^+$ ions 12.88 times lower compared to the water brands marketed in the state of Pará.

**Table 3**

*pH and electrical conductivity of water sold in the state of Pará*

| Municipalities | pH | | | Electrical conductivity (µS.cm$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Minimum | Maximus | Mean ± SD | Minimum | Maximus | Mean ± SD |
| Bethlehem | 4.40 | 4.91 | 4,60 ± 0,21 | 165.9 | 175.2 | 170.1 ± 3.8 |
| Ananindeua | 4.61 | 4.98 | 4.77 ± 0.14 | 81.2 | 101.7 | 87.6 ± 7.6 |
| Benevides | 4.72 | 5.40 | 4,85 ± 0,33 | 31.0 | 32.0 | 31.6 ± 0.4 |
| Izabel of Pará | 4.08 | 4.41 | 4.27 ± 0.12 | 32.0 | 38.4 | 33,5 ± 2,8 |
| Brazil nut | 4.09 | 4.26 | 4.17 ± 0.06 | 187.3 | 219.7 | 202.4 ± 11.6 |
| Watch | 4.89 | 5.27 | 5,01 ± 0,11 | 20.7 | 21.4 | 20,1 ± 0,3 |
| Maraba | 5.61 | 6.05 | 5,85 ± 0,19 | 39.1 | 40.3 | 39.8 ± 0.4 |
| Santarém | 4.75 | 4.87 | 4,81 ± 0,04 | 15.2 | 16.9 | 16.2 ± 0.7 |
| **Overall Mean ± SD** | **4.65 ± 0.33** | | | **66.7 ± 62.4** | | |

When comparing the average values of electrical conductivity of treated rainwater (25.9 ± 15.4 µS.cm$^{-1}$) with the average values of water marketed in the state of Pará (66.7 ± 62.4 µS.cm$^{-1}$), significant differences were observed. In addition, when comparing individual values, it is observed that two brands presented values above the standard established by CETESB. In addition, the cities of Belém and Castanhal presented mean and maximum values of concern, as shown in Table 3.

## 4.2 TOTAL COLIFORMS AND *ESCHERICHIA COLI*

In untreated natural waters, the presence of microorganisms is normal and fundamental, since they are part of the food chain, essential for the biochemical processes of organic matter degradation and nutrient cycling (Esteves, 2011). However, these are related to the possibility of transmission of waterborne diseases. According to Von Sperling (2011), the determination of the potential of water to transmit diseases can be performed indirectly, through the indicator organisms of faecal contamination, mainly belonging to the coliform group. Among the indicators of faecal contamination commonly used are total coliforms, faecal coliforms and faecal streptococci. Although total coliforms do not necessarily pose risks to human health, they are not desirable in drinking water, as they are usually associated with other pathogenic organisms (Barcellos & Bollman, 2013). Ordinance GM/MS n. 888 (2021) of the Ministry of Health considers that any type of coliform must be absent in water for human consumption.

In this study, it was observed that the natural waters collected directly from the reservoirs, without treatment, presented total coliforms in 94.8% of the samples; presence of *Escherichia coli* in 64.1%, and absence of contamination in 5.2% of the samples (Table 4). Water contamination is usually associated with the care of the entire system, from the catchment area to the final treatment. For better water quality, it is recommended to periodically clean (every 30 days) the roof, gutters, water reservoirs and dispose of the first millimetre of water at each rainfall event, *necessary for the cleaning of the catchment area (Neu et al.*, 2018; Abdulla & Al-Shareef, 2009).

**Table 4**

*Presence or absence of total coliforms and Escherichia coli in natural rainwater, without treatment and post-treatment.*

| Collections | R1 | R2 | R3 | R4 | R5 | R6 | R7 | Rr |
|---|---|---|---|---|---|---|---|---|
| | Untreated | | | | | | | |
| Campaign 1 | · | | · · | · | · · | · · | - | · |
| Campaign 2 | · · | · | | · · | · · | · · | - | · |
| Campaign 5 | - | - | · · | · | · · | · · | · · | · · |
| Campaign 6 | · · | - | · · | · | · · | · · | · · | · |
| Campaign 7 | · · | - | · | · · | · · | · · | · · | · |
| Campaign 8 | · · | - | - | · | - | · · | · | · · |
| | Post-treatment | | | | | | | |
| Campaign 1 | | | | | · · | · · | - | |
| Campaign 2 | · · | · | | | · · | · | - | |
| Campaign 5 | - | - | | | · | · ·* | · ·* | · |
| Campaign 6 | · | - | · | | · | · · | · | |
| Campaign 7 | | - | | · | · | | · | |
| Campaign 8 | | - | - | · | - | · · | ·* | |

**Legend:** · · Faecal and total coliform contamination; · Total coliform contamination only; □No coliform contamination; - Not analysed, no sampling; * No sodium hypochlorite use.

After water treatment, a reduction in microbiological contamination was observed. However, total coliforms were still detected in 53.8% of the samples analysed, while *Escherichia coli* was present in 20.5% of the samples. There was also a significant increase in the proportion of samples free of biological contamination, which increased to 46.2% after treatment (Table 4).50% of the homes evaluated did not present contamination by *Escherichia coli* after treatment, while the others presented sporadic contamination. The absence of *E. coli* contamination in R2, R3, R4 and Rr suggests that, when correctly conducted, the treatment system is effective. It is noteworthy in Rr, where periodic cleaning of the system was performed, *Escherichia coli* was absent in 75% of the samples without treatment and was not detected in any of the post-treatment samples. However, when the control system did not receive sanitation for a period of 30 days, as part of the experiment to verify potential contaminants due to lack of maintenance, the presence of *E. Coli* was observed in the water samples (Campaigns 5 and 8).

The positive results for coliforms and *Escherichia coli* found in the samples after treatment, possibly, may be associated with the lack of good maintenance practices and hygiene of water collection and storage systems. Although technical guidelines have been passed on at the time of system implementation and throughout monitoring, factors such as lack of habit, inattention, *cultural influences and even rejection of certain treatment methods may have compromised the efficiency of the process.* These conditions may favour microbiological contamination, the presence of pathogens in part of the samples, emphasising the importance of awareness and correct management of the system to ensure adequate quality of drinking water. The presence of total coliforms and *Escherichia coli* was observed in several studies with rainwater harvesting systems. Teixeira *et al.* (2015) observed the presence of total coliforms and *Escherichia coli* in a residential rainwater harvesting system in the state of São Paulo. Silva *et al.* (2014), in a study carried out in several states of the Brazilian semiarid region (Bahia, Piauí, Pernambuco, Rio Grande do Norte, Sergipe, Alagoas, Ceará and Paraíba), observed the presence of coliforms in the waters captured. Abdulla and Al-shareef (2009), in a study conducted in Jordan, also found the presence of total coliforms in the water of the tanks in the homes.

## 4.3 CHARACTERISATION OF METALS

In general, the concentration of metals was very low, of the 1976 quantifications carried out, 90.5% were below the limit of quantification of the equipment (Table 5), an indicative of a good air quality environment. The study area, both urban and rural, which is approximately 5 km from Belém, show no signs of polluted atmosphere. The low industrialisation and the presence of remnants of still conserved forest are factors that contribute to the air quality in the region, which can be perceived even in the urban area, due to the presence of lichens, bioindicators of air quality (Maki *et al.*, 2013).

**Table 5**

*Concentration of metals present in rainwater, without treatment and after treatment.*

| Metals (mg/L) | Untreated | | | Post-treatment | | | VMP (Port. 888) |
|---|---|---|---|---|---|---|---|
| | % above of VMP | Minimum | Maximus | % above of VMP | Minimum | Maximus | |
| Aluminium (Al) | 3.84 | <0.0100* | **0.4513** | 1.92 | <0.0100* | **0.2304** | 0.2000 |
| Arsenic (Ar) | 0 | <0.0010* | <0.0010* | 0 | <0.0010* | <0.0010* | 0.0100 |
| Barium (Ba) | 0 | <0.0050* | 0.0067 | 0 | <0.0050* | 0.0080 | 0.7000 |
| Cobalt (Co) | 0 | <0.0500* | <0.0500* | 0 | <0.0500* | <0.0500* | - |
| Cadmium (Cd) | 0 | <0.0003* | <0.0003* | 0 | <0.0003* | <0.0003* | 0.0030 |
| Copper (Cu) | 0 | <0.0010* | 0.0112 | 0 | <0.0010* | 0.0332 | 2.0000 |
| Chromium (Cr) | 0 | <0.0050* | <0.0050* | 0 | <0.0050* | <0.0050* | 0.0500 |
| Iron (Fe) | 0 | <0.0050* | 0.0509 | 0 | <0.0050* | 0.0209 | 0.3000 |
| Mercury (Hg) | 0 | <0.0005* | <0.0005* | 0 | <0.0005* | <0.0005* | 0.0010 |
| Manganese (Mn) | 0 | <0.0050* | 0.0262 | 0 | <0.0050* | 0.0131 | 0.1000 |
| Molybdenum (Mo) | 0 | <0.0050* | <0.0050* | 0 | <0.0050* | <0.0050* | - |
| Nickel (Ni) | 0 | <0.0050* | 0.0098 | 0 | <0.0050* | <0.0050* | 0.0700 |
| Lead (Pb) | 0 | <0.0010* | 0.0069 | 0 | <0.0010* | 0.0065 | 0.0100 |
| Antimony (Sb) | 0 | <0.0010* | <0.0010* | 0 | <0.0010* | 0.0031 | 0.0060 |
| Selenium (Se) | 0 | <0.0010* | <0.0010* | 0 | <0.0010* | <0.0010* | 0.0400 |
| Titanium (Ti) | 0 | <0.0010* | <0.0010* | 0 | <0.0010* | <0.0010* | - |
| Uranium (U) | 0 | <0.0010* | <0.0010* | 0 | <0.0010* | <0.0010* | 0.0300 |
| Vanadium (V) | 0 | <0.0050* | <0.0050* | 0 | <0.0050* | <0.0050* | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Zinc (Zn) | 0 | <0.0050* | 1.1504 | 0 | <0.0050* | 0.5562 | 5.0000 |

**Caption:** *Values below the detection limit; **Values above the VMP**.

The metals arsenic, cadmium, cobalt, chromium, mercury, molybdenum, selenium, titanium, uranium and vanadium presented concentrations below the limit of quantification of the equipment in all samplings (Table 4). Silva (2021), who evaluated the concentration of metals in an urban area of Manaus, also did not detect the presence of arsenic, chromium and selenium in rainwater. Of the natural waters without treatment, it was verified that only two samples presented aluminium concentrations above the established by Ordinance GM/MS n. 888 (2021) of the Ministry of Health (Table 4). While, after treatment, only one sample had aluminium values slightly above those established by the ordinance (Table 4).

The presence of other metals such as copper, iron, manganese, lead, barium, nickel and zinc was observed in rainwater, but at concentrations below what Ordinance GM/MS n. 888 (2021) establishes. Cerqueira *et al.* (2014), in a study conducted in Juiz de Fora (MG), also found zinc and copper values in rainwater. The presence of nickel and zinc, in low concentrations, may be associated with the proximity of the urban area, where diesel combustion processes, abrasion of rubber tyres and asphalt wear can cause the release of these metals (Ozaki, Watanabe & Kuno, 2004).

Unlike this study, in regions of intense industrialisation such as China, air contamination is worrying, seriously affecting the quality of rainwater, due to the presence of trace metals such as lead, in addition to high acidity (Ying, 2004). In Iran, Tehran region, high concentrations of metals were also recorded by Malekei *et al.* (2024) in rainwater (5.292 ± 1.536 mg $L^{-1}$ of Zn; 1.455 ± 0.462 of Pb and 1.184 ± 0.04 of Cu). Air pollution in Iran has been recorded as a mortality risk factor, associated with cardiovascular disease, lung cancer, pharyngitis and bronchitis (Khoshakhlagh, Mohammadzadeh & Morais, 2023). Due to the serious health impacts, monitoring of metals in rainwater, especially in regions impacted by industrial or agricultural processes, is essential to avoid adverse effects on human health.

## 5 CONCLUSION

The results of this study reinforce the need for proper treatment of rainwater intended for human supply. Although the rainwater collected in the analysed region presents physical-chemical and biological characteristics within the environmental standards, its potability is not guaranteed without a proper treatment. The presence of microorganisms can pose significant risks to public health because it can cause waterborne diseases.

The treatment by adding sodium hypochlorite proved to be effective in biological disinfection, provided that the protocols are strictly followed. In addition, the filtration using polypropylene candle and activated carbon proved to be efficient in removing the residual flavour and reducing the acidity of the water, approaching its values to the standards of potability established by legislation.

Another relevant aspect observed was the low electrical conductivity and the reduced concentration of metals in the analysed samples indicating that the atmosphere of the region still presents favourable characteristics for the formation of rain with quality. However, despite the feasibility of using rainwater, some samples showed divergences in relation to normative parameters, such as pH and the appearance of coliforms, highlighting the importance of continuous maintenance of water catchment systems and regular water monitoring.

Thus, this study shows that rainwater harvesting as a social technology can be effective to promote access to good quality drinking water to communities facing supply-related difficulties. The implementation and encouragement of the use of these technologies, combined with the strategy of environmental education and population awareness, can contribute significantly to ensuring water security and improving the quality of life in regions with low coverage of basic sanitation.

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## REFERENCES

Abdulla, F. A., & Al-Shareef, A. W. (2009). Roof rainwater harvesting systems for household water supply in Jordan. *Desalination*, *243*(1-3), 195-207.

Andrade, A. L. M. (2009, novembro). Avaliação da potabilidade das águas pluviais utilizadas para consumo humano na comunidade Nossa Senhora de Fátima do Jandira, Iranduba – AM. In *Anais do 18o Simpósio Brasileiro de Recursos Hídricos*, Campo Grande, MT.

Andreae, M. O., & Crutzen, P. J. (1997). Atmospheric aerosols: Biogeochemical sources and role in atmospheric chemistry. *Science*, *276*(5315), 1052-1058.

Araújo, M. G. S., & Neu, V. (2024). Saneamento em comunidades ribeirinhas na Amazônia. In Bastos, R. K. X. (Coord.), *Direitos Humanos à Água e ao Saneamento no Brasil* (pp. 134 – 137). Brasília, DF: ONDAS.

Baird, C., & Cann, M. (2011). *Environmental Chemistry*. Editora W. H. Freeman.

Barcellos, D. S., & Bollmann, H. A. (2013, setembro). Mapeamento da qualidade bacteriológica das águas superficiais nas trilhas de acesso ao pico Marumbi, Parque Estadual do Marumbi, Morretes, Paraná. In *27o Congresso Brasileiro de Engenharia Sanitária e Ambiental*, Goiânia, GO.

Basta, P. C., Dias, A. P., & Boemer, G. L. C. (2024). *No caminho das águas, a retomada da saúde Yanomami: Relatório Final*. Recuperado de https://arca.fiocruz.br/items/e819e60e-8b11-4894-87ca-54a120f9aa66

Boesch, D. F. (2002). Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems. *Estuaries*, *25*(4), 886-900.

Bordalo, C. A. (2017). O paradoxo da água na região das águas: o caso da Amazônia brasileira. *GEOUSP Espaço e Tempo (Online)*, *21*(1), 120-137.

*Portaria GM/MS n. 888, de 4 de maio de 2021*. (2021). Altera o Anexo XX da Portaria de Consolidação GM/MS nº 5, de 28 de setembro de 2017, para dispor sobre os procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. Brasília, DF. Recuperado de https://bvsms.saude.gov.br/bvs/saudelegis/gm/2021/prt0888_07_05_2021.html

Brinkmann, W. L. F., & Santos, A. D. (1973). Natural waters in Amazonia. VI-soluble calcium properties. *Acta Amazonica*, *3*(2), 33-40.

Cerqueira, M. R. F., Pinto, M. F., Derossi, I. N., Esteves, W. T., Santos, M. D. R., Matos, M. A. C., ... & Matos, R. C. (2014). Chemical characteristics of rainwater at a southeastern site of Brazil. *Atmospheric Pollution Research*, *5*(2), 253-261.

CETESB - Companhia Ambiental do Estado de São Paulo. (2011). *Guia nacional de coleta e preservação de amostras*. Recuperado de https://cetesb.sp.gov.br/wp-content/uploads/2021/10/Guia-nacional-de-coleta-e-preservacao-de-amostras-2012.pdf

Costa, C. M. O., dos Santos, D. F., Bulhões, T. M. P., de Oliveira, J. O., Gusmão, B. R., de Oliveira, J. B. V., ... & Costa, C. R. B. (2021). Perfil epidemiológico da diarreia em crianças de 1 a 4 anos no estado de Alagoas. *Revista de Atenção à Saúde*, *19*(68).

Cunha, G. R. D., Santi, A., Dalmago, G. A., Pires, J. L. F., & Pasinato, A. (2009). Dinâmica do pH da água das chuvas em Passo Fundo, RS. *Pesquisa Agropecuária Brasileira*, *44*, 339-346.

Dias, R. B. (2013). Tecnologia social e desenvolvimento local: reflexões a partir da análise do Programa Um Milhão de Cisternas. *Revista brasileira de desenvolvimento regional*, *1*(2), 173-189.

Esteves, F. (2011). *Fundamentos da Limnologia*. Editora Interciência.

IBGE – Instituto Brasileiro de Geografia e Estatística. (2020). *Pesquisa nacional de saneamento básico 2017: Abastecimento de água e esgotamento sanitário - Plataforma SIDRA*. Recuperado de https://sidra.ibge.gov.br/pesquisa/pnsb/pnsb-2017

INCRA - Instituto Nacional de Colonização e Reforma Agrária. (2025). *Projetos de reforma agrária conforme fases de implementação*. Recuperado de https://www.gov.br/incra/pt-br/assuntos/reforma-agraria/assentamentosgeral.pdf

Instituto Nacional de Meteorologia. (2025). *Dados anuais históricos de precipitação da estação de Belém – PA (A201), período de 2000-2024*. Recuperado de https://portal.inmet.gov.br/dadoshistoricos

Júnior, P. C. B. (2018). *Água da chuva: aproveitamento para a gestão de recursos pluviais em comunidades ribeirinhas do estado do Amazonas* (2018). Universidade do estado do Amazonas.

Khoshakhlagh, A. H., Mohammadzadeh, M., & Morais, S. (2023). Air quality in Tehran, Iran: Spatio-temporal characteristics, human health effects, economic costs and recommendations for good practice. *Atmospheric Environment: X*, *19*, 100222.

Maki, E. S., Shitsuka, R., Barroqueiro, C. H., & Shitsuka, D. M. (2013). Utilização de Bioindicadores em monitoramento de poluição. *Biota Amazônica, Macapá*, *3*(2), 169-178.

Malekei, R., Sayadi, M. H., Behrooz, R. D., & Kaskaoutis, D. G. (2024). Toxic heavy metals in rainwater samples of Tehran. *Journal of Atmospheric Chemistry*, *81*(1), 3.

Marques, R., Zamparoni, C. A., Silva, E. D. C., Magalhães, A. D., Guedes, S. F., & Fornaro, A. (2010). Composição química de águas de chuva em áreas tropicais continentais, Cuiabá-MT: aplicação do sistema clima urbano (SCU). *Revista do departamento de Geografia*, *20*, 63-75.

May, S. (2004). *Estudo da viabilidade do aproveitamento de água de chuva para consumo não potável em edificações* (Dissertação de Mestrado). Universidade de São Paulo.

Moreira, J. C., Peres, F., Simões, A. C., Pignati, W. A., Dores, E. D. C., Vieira, S. N., ... & Mott, T. (2012). Contaminação de águas superficiais e de chuva por agrotóxicos em uma região do estado do Mato Grosso. *Ciência & Saúde Coletiva*, *17*, 1557-1568.

Neu, V., Guedes, V. M., Araújo, M. G. D. S., Meyer, L. F. F., Brito, I. R., & Batista, L. M. (2018). Água da chuva para consumo humano: estudo de caso na Amazônia Oriental. *Inclusão Social*, *12*(1), 183-198.

Neu, V. (2009). *O ciclo do carbono na bacia do Alto Xingu: interações entre ambientes terrestre, aquático e atmosférico* (Tese de Doutorado). Universsidade de São Paulo.

ONU - Organização das Nações Unidas. (2015). *A Agenda 2030*. Recuperado de https://nacoesunidas.org/pos2015/agenda2030/

Ozaki, H., Watanabe, I., & Kuno, K. (2004). Investigation of the heavy metal sources in relation to automobiles. *Water, Air, and Soil Pollution*, *157*(1), 209-223.

Di Blasi, J. P., Torres, J. M., Nieto, P. G., Fernández, J. A., Muñiz, C. D., & Taboada, J. (2013). Analysis and detection of outliers in water quality parameters from different automated monitoring stations in the Miño river basin (NW Spain). *Ecological engineering*, *60*, 60-66.

Sacadura, F. O. M. O. (2011). *Análise de sistemas de aproveitamento de água pluvial em edifícios* (Dissertação de Mestrado). Universidade Nova de Lisboa.

Silva, A. S., Fay, E. F., Sá, I. B., & Brito L. T. L. (2014, agosto). PERFIL DO SEMIÁRIDO RURAL BRASILEIRO: Avaliação microbiológica das águas de uso domiciliar. In *Anais do 9o Simpósio Brasileiro de Captação e Manejo de Água de Chuva*, Feira de Santana, BA.

Silva, L. F. M. (2021). *Estudo da deposição atmosférica úmida no campus da Universidade Federal do Amazonas* (Dissertação de Mestrado). Universidade Federal do Amazonas.

Silvério, H. L. M., Dias, J. T., Santos, A. P., Araújo, M. L. D., & Ferreira, N. L. (2024). Insegurança alimentar e acesso irregular à água potável: um panorama da realidade brasileira. *Revista Brasileira de Estudos de População*, *41*, e0264.

Stallard, R. F., & Edmond, J. M. (1981). Geochemistry of the Amazon: 1. Precipitation chemistry and the marine contribution to the dissolved load at the time of peak discharge. *Journal of Geophysical Research: Oceans*, *86*(C10), 9844-9858.

Stradioto, M. R. (2004). *Estudo hidroquímico das águas superficiais e de chuva na área de ocorrência da formação Rio Claro no município de Rio Claro/SP* (Tese de Doutorado). Universidade Estadual Paulista.

Teixeira, A. D. S., Pulz, E., Silva, B. C. R., Irazusta, S. P., & Teixeira, E. P. (2015, outubro). Avaliação da qualidade de água de chuva para aproveitamento doméstico. In *10o Workshop de pós-graduação e pesquisa do centro Paula de Sousa*, São Paulo, SP.

Veloso, N. D. S. L., & Mendes, R. L. R. (2014). Aproveitamento da água da chuva na Amazônia: experiências nas ilhas de Belém/PA. *Revista Brasileira de Recursos Hídricos*, *19*(1), 229-242.

Veloso, N. D. S. L., Mendes, R. L. R., de Oliveira, D. R. C., & da Costa, T. C. D. (2012). Água da chuva para abastecimento na Amazônia. *Movendo Ideias*, *17*(1).

Von Sperling, M. (2014). *Estudos de modelagem da qualidade da água de rios*. Editora UFMG.

Von Sperling, M. (2011). *Introdução à qualidade das águas e ao tratamento de esgotos*. Editora UFMG.

WHO - World Health Organization. (2022**).** *State of the world's drinking water: An urgent call to action to accelerate progress on ensuring safe drinking water for all*. Recuperado de https://www.who.int/publications/i/item/9789240060807

Ying, Z. (2004). Desafios da China: Desenvolvimento Econômico e Poluição Ambiental. In Bellucci, B. (Org.), *Abrindo os olhos para a China* (pp. 123 – 157). Rio de Janeiro, RJ: Editora Educam.