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Assessment of water quality for human consumption in the municipality of Manicoré-am

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The assessment of water quality for human consumption is of utmost importance due to the crucial role water plays in public health. Therefore, the objective of this study was to evaluate the quality of water for human consumption in the municipality of Manicoré/AM. A survey of the semi-artesian wells supplying the city was conducted. The sampling took place during the rainy season, and six sampling points were selected, where the following parameters were determined: a) microbiological: thermotolerant coliforms and total coliforms; b) physical: apparent color and turbidity; c) chemical: Total iron and total manganese. After laboratory analyses, the results were compared with the values established by ordinance No. 888/2021 of the Ministry of Health. The results indicated that point 6, located in the Santa Luzia neighborhood, revealed the presence of total and thermotolerant coliforms, as well as values above the maximum contaminant level for apparent color and turbidity. Point 1, located at the Municipal Guard station in the Manicorezinho neighborhood, also indicated the presence of total coliforms. The evaluation of the parameters of the two sampling points (1 and 6) demonstrated that the water from the wells is unsuitable for human consumption.

Keywords Improper use of water, Contamination of water bodies, Public health

Water is an essential element for human consumption, playing crucial roles in maintaining health and ensuring the proper functioning of the body. Besides being fundamental for hydration and temperature regulation, water is also vital for digestion and nutrient absorption. Water scarcity can lead to a range of health issues, highlighting its importance as an indispensable resource for human life.

According to[1] water is a vital natural resource for the survival of all forms of life, including humans, animals, and plants. However, Brazil, despite being a country rich in water resources, exhibits an uneven distribution of these resources, particularly when comparing the North and Northeast regions. In this context[2] note that in areas characterized by drought, such as the Brazilian cerrado, one of the main methods of obtaining water is through the drilling of shallow and deep wells and the use of cisterns. Approximately 39% of municipalities in Brazil rely on groundwater.

Improper use of water can lead to various consequences, including waterborne diseases[3]. emphasized the need for rigorous monitoring to maintain hygiene and microbiological control of water reservoirs, along with preventive and corrective measures such as water treatment, periodic cleaning, and maintenance of reservoirs, filters, and drinking fountains. Additionally, monitoring reveals that contamination is often due to poor allocation and inadequate construction of water collection systems, as well as a lack of maintenance of supply systems.

Until the enactment of Ministry of Health Ordinance No. 888[4], the water quality standards in the country were defined by Ministry of Health Ordinance No. 2,914[5], dated December 12, 2011 which specifically focused on issues such as turbidity, the presence of coliforms, cyanotoxins, and certain chemical substances. However, as we have seen, emerging contaminants are of recent discovery; therefore, the ten-year interval has rendered these parameters obsolete and inadequate for the current reality. Currently, pharmaceuticals, pesticides, trace metals, cosmetics, hormones, caffeine, detergents, disinfectants, industrial wastes, and microplastics are major examples of emerging contaminants. According to[6], conventional treatment techniques are employed to address these contaminants but fail to eliminate them due to the polar characteristics found in many of them. A treatment technology that has shown promising results in removing these residues is advanced oxidation processes (AOPs), which are also economically viable[7]. Other technologies that can also be mentioned include activated

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carbon adsorption and membrane filtration. Research by[8,9]. highlights the importance of studying surface and groundwater to compare with current regulations, as both studies reveal deficiencies relative to Brazilian potable water standards due to lack of planning by authorities and public awareness.

The Amazon Hydrographic Region (AHR) accounts for approximately 80% of the country's surface water and provides water supply to around 4.3 million inhabitants of Amazonian cities. Major uses include rural supply (4.0%), mining (0.3%), thermoelectric power (49.6%), irrigation (4.3%), human consumption (37.0%), animal use (3.11%), and others (1.31%)[10].

In the Amazon region, the phenomenon known as the "flood pulse" plays a significant role in the aquatic environment, affecting physical conditions and ecological processes[11,12], and influencing water quality in both natural and urbanized areas [13]. Another important characteristic of the region is the unique nature of its rivers, with distinct lengths, colors, and patterns. Therefore, local variables should be respected and considered when applying environmental regulations with standardized values, necessitating the creation of environmental legislation that addresses the classification of Amazonian rivers[14,15]. Still in the Amazon region, while investigating the quality of the surface waters of "Lago Preto" in the municipality of Lábrea/AM,[16] concluded that the water quality index of this body of water was classified as "poor"; it is worth noting that this water is used to supply the local population. Studies focused on water quality in municipalities in the Amazon region are scarce, particularly in remote areas, and research on this topic aligns with SDG 6 of the United Nations (UN)[17].

The objective of this study was to analyze and evaluate the quality of water intended for human consumption in the municipality of Manicoré—AM, taking into account a comprehensive approach to physical, chemical, and microbiological parameters.

Methodology

Study area characterization

The study area is located in the municipality of Manicoré-AM, as illustrated in Fig. 1, with coordinates: Latitude: 5° 48′ 34" S, Longitude: 64° 18′ 2" W. Situated in the Southern Amazon mesoregion and the Madeira microregion, it borders the municipalities of Beruri, Borba, Humaitá, Novo Aripuanã, and Tapauá. With a population of

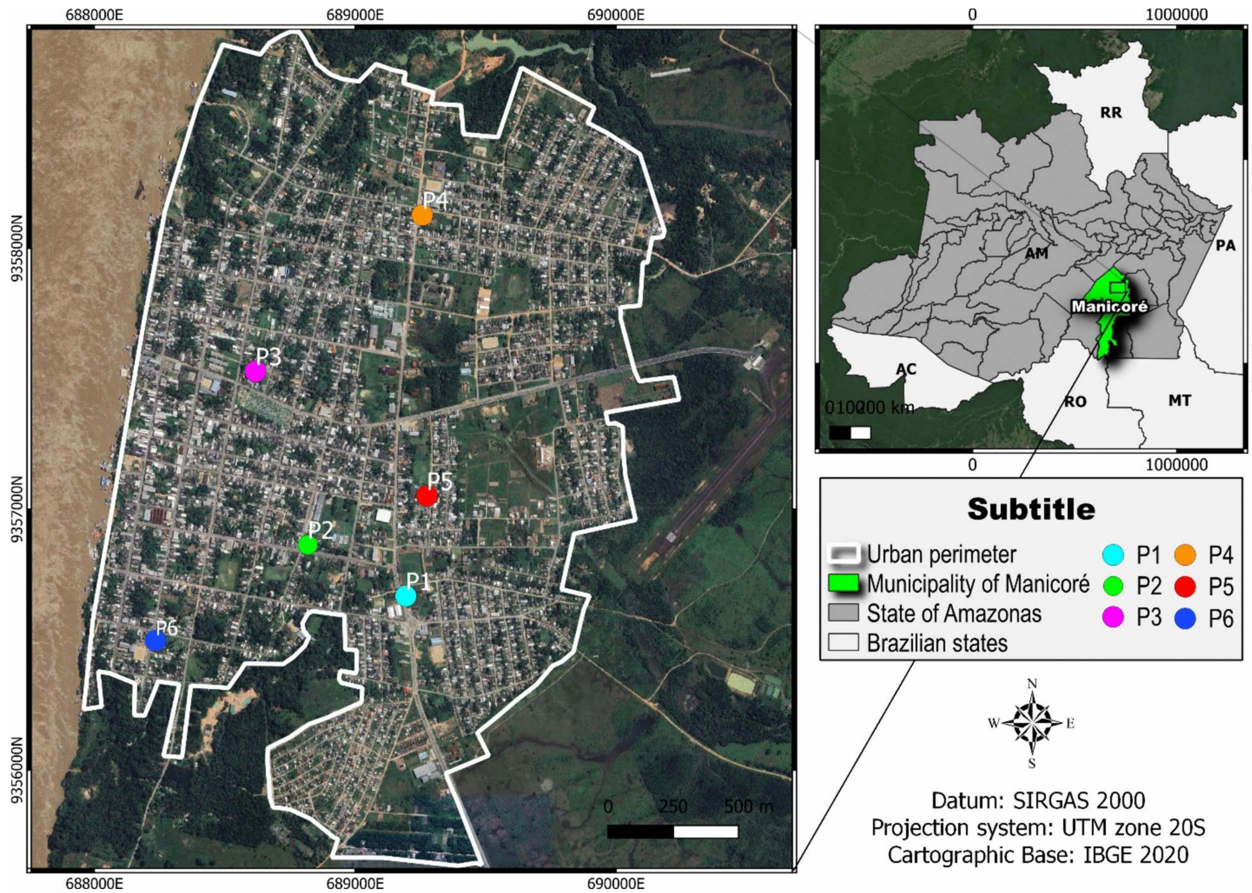

Fig. 1. Location and Sampling Points in the Municipality of Manicoré – AM, image created by the author Eliezer Lucio Fernandes Lima with the GIS software QGIS desktop 3.16.4 with GRASS 7.8.5 free version, the satellite image is from the Web-QuickMapServices plugin using a free image from Google services, for the image of the Municipal, State, and Federal boundaries, Shapefile files were used, freely available on the website of the Brazilian Institute of Geography and Statistics – IBGE. Source: Eliezer Lucio Fernandes Lima (2024).

57,405 inhabitants and an area of 48,315.038 km^2, the municipality is located on the right bank of the Madeira River, 332 km from Manaus[18].

The region's climate, according to the Köppen classification, is characterized a tropical humid, with a prolonged rainy season and a short dry period, occurring between June and August. The average annual temperature is 25 °C, and the average annual rainfall is 2,500 mm[19].

Sampling procedure

Sampling took place in December 2023, during the rainy season. To identify the sampling points, Garmin GPS equipment, model etrex 10, was used to locate points P1, P2, P3, P4, P5., and P6 distributed throughout the city, which were georeferenced. Following this step, photographic records were made, and observations of the water distribution sites were conducted. The procedures for collecting water samples adhered to the methodologies described in ANA Resolution No. 724/2011, which defines the "National Guide for Sampling and Preservation of Water, Sediments, Aquatic Communities, and Liquid Effluents." Gloves were used to avoid direct contact with the samples, as illustrated in Fig. 2.

Figure "b)" shows two water sampling points where samples are collected directly from the faucet and are accessible to the public. These wells are located at the Municipal Guard Station in the Manicorezinho neighborhood and at the City Council in the Auxiliadora neighborhood. Figures "a," "c," "d," and "e" depict the semi-artesian wells that supply water to the neighborhoods.

Previously, before going to the municipality for collection, all containers were sterilized in a laboratory with distilled water and stored in appropriate places so that there would be no contamination of the samples, compromising the study. For each sample, the following collection procedure was adopted: a) the faucets and containers were pre-cleaned with distilled water, and prior to sampling, maximum flow was allowed for 3 min. Each sample was then transferred into two distinct plastic containers, one with a capacity of 100 mL and the other with 150 mL, both properly labeled. Subsequently, the samples were carefully stored in a thermal polystyrene container to maintain the temperature at or below 4 °C during transport to the Sanitation Laboratory at the Institute of Education, Agriculture, and Environment (IEAA/UFAM) and to the LAPEF laboratory located in Humaitá/AM and Porto Velho/RO, respectively.

The samples were taken to the LAPEF laboratory, which features modern facilities and equipment and adheres to a rigorous quality control system, ensuring that analyses are performed with quality, traceability, speed, and efficiency. The laboratory meets the requirements specified in NBR ISO/IEC 17025:2005, taking into account all necessary technical specifications from the collection stage to the issuance of the report, which can be accessed directly by our clients through our website, guaranteeing accuracy, reliability, and the lowest quantification limits and measurement uncertainties available on the market."

Fig. 2. Presentation of water collection points in the Municipality of Manicoré, carried out by the author Eliezer Lucio Fernandes Lima. Source: The Authors (2024).

Sampling points	Description of the points	Geographic coordinates	
		Latitude	Longitude
Point 1	Manicorézinho Neighborhood	5°49′3.56"S;	61°17′28.56"O
Point 2	Auxiliadora Neighborhood	5°48′57.42"S;	61°17′40.69"O
Point 3	Centro Neighborhood	5°48′35.52"S;	61°17′47.38"O
Point 4	São Sebastião Neighborhood	5°48′15.90"S;	61°17′26.77"O
Point 5	Mazzarelo II Neighborhood	5°48′51.18"S;	61°17′25.88"O
Point 6	Santa Luzia Neighborhood	5°49′9.16"S;	61°17′59.74"O

Table 1. Geographic location of sampling points. Source: The Authors (2024).

Points	Description
P1	Well located at the Municipal Guard post in the Manicorézinho neighborhood,
P2	Well located at the municipal chamber in the Auxiliadora neighborhood
P3	The well is located in the Autonomous Water and Sewage System (Siságua), an entity responsible for all public supply wells in the municipality, supplying the neighborhoods of Centro, Mazzarelo, Domingo Sávio, part of Santa Luzia, and Auxiliadora. The well has been in operation since 2009, with a depth of 90 m and maintenance every 2 months
P4	Well located near the Aristeu Virgolino school in the Rosário neighborhood, with a depth of 150 m. The well supplies the neighborhoods of São Sebastião, Andaraí, Santo Antônio, Presidente Lula, and a large part of Mazzarelo, with maintenance every 3 months
P5	Well located in the Mazzarelo II neighborhood with a depth of 150 m, supplies the neighborhoods of Andaraí and Presidente Lula
P6	Well located in the Santa Luzia neighborhood, with a depth of 150 m. The well supplies the neighborhoods of Rocinha, Manicorézinho, and part of Centro

Table 2. Location of wells of sampling points. Source: The Authors (2024).

Characterization of sampling points

The careful selection of locations for collecting water intended for human consumption, which is subject to laboratory analysis to verify its potability, is crucial for identifying potential contaminant influences. This proactive approach ensures that possible sources of contamination at the collection site are considered, thereby ensuring that laboratory results accurately reflect the true quality of the water. It underscores the intrinsic importance of combining efforts to protect human health and preserve the environment, as detailed in Tables 1 and 2

Currently, all the wells listed in Table 2 are operated by the Autonomous Water and Sewage System (SISAGUA). The city government has already carried out water analyses; however, the data has not been made available. Furthermore, there is no regular monitoring of water quality, nor do the wells receive specific treatments, such as chlorine dosing, to ensure potability. Although these artesian wells may have been constructed in compliance with Brazilian standards NBR 12,212 and NBR 12,244, there is no evidence that they are under continuous operational control or technical monitoring to maintain water quality standards. According to the person responsible for the public water supply, maintenance of the wells only includes checking the condition of the pump and physical structure. The water supply is metered, with a fixed rate for residences around R$18, while businesses, commercial establishments, apartments, and other places with higher water consumption are subject to variable rates around R$25.

Planning, collection, analysis, and data interpretation

The development of this work followed these steps: (a) preparation of the literature review, which involves researching and critically analyzing literature related to the topic to theoretically support the study; (b) planning the data collection, which defines methods, equipment, locations, and schedules for data gathering; (c) mapping and georeferencing, which detail the study area using technologies such as GPS and software, while photographic documentation visually records the process.

The definition of the collection points was based on the urban portion of the municipality, with the aim of representing the study area. Based on this planning, the collection, handling, and storage of water samples adhered to the protocols established by the Practical Manual for Water Analysis from FUNASA[20].

Laboratory analyses examined the samples to determine the physicochemical and microbiological characteristics of the water, with the techniques used detailed in Table 3.

Subsequently, the results led to discussions and final considerations, guided by legislation and existing literature, highlighting contributions, limitations, and recommendations for future studies.

After the collection stages were completed, the obtained data were organized and systematized in Excel spreadsheets to create graphs and tables. The graphs were generated using the matplotlib library from the Python 3.9 programming language, a programming language that allowed for a more dynamic and interactive visualization of the results, facilitating the identification of relevant patterns and trends.

Results and discussion

The system used for water distribution in the municipality under study is the drinking water supply system (SAA), where the samples were collected. The wells are close to residences and have a poor sewage treatment

Parameter	Methodology	Reference
Apparent Color	Method 2120E	SMWW 24th edition, 2023
Turbidity	Method 2130B	SMWW 24th edition, 2023
Total Iron	Method Photocolorimeter	FRIES, J. GETROST, H. ORTA; 1977, p. 204
Total Manganese	Method Formaldoxin	FRIES, J. GETROST, H. MERCK; 1977, p. 236
Total Coliforms	Method 9223 B	SMWW 24th edition, 2023
Thermotolerant Coliforms	Method 9221 B, C, D and E	SMWW 24th edition, 2023

Table 3. Techniques used to analyze samples in the laboratory. Source: The Authors (2024).

Parameters	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	MPV
Apparent color	< 5,0	< 5,0	< 5,0	< 5,0	< 5,0	**44,2**	up to 15 uH*
Turbidity	< 1,0	< 1,0	< 1,0	1,13	< 1,0	**47,00**	up to 5,00 UNT*
Total iron	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	up to 0,30 mg/L*
Total manganese	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	up to 0,10 mg/L*

Table 4. Assessment of physicochemical Parameters of Water in the Municipality of Manicoré/AM; MPV (*):Maximum Permissible values according to Ordinance No. 888/21. Source: The Authors (2024).

system, known as "cesspits." Based on the assessment of the studied variables, the results were compared with Ministry of Health Ordinance No. 888/2021, which establishes the compliance criteria for drinking water (Table 4).

Among the parameters studied, the results for the variables Iron and Total Manganese remained in compliance with the current legislation for all the wells analyzed [21]. emphasize the importance of these parameters being regulated by legislation, noting that while the presence of iron and manganese, in concentrations typically found, may not cause health issues, it can undermine public trust in the treatment system.

Of all the analyzed wells, well 6 showed values above the permitted limits for the variables: Apparent Color and Turbidity. Elevated turbidity values can indicate that the water may be unsuitable for consumption, as it may contain particles and microorganisms; the research result showed a value 8 times higher than the limit set by Portaria No. 888/2021. Similar results were found by[22] who, in a study of water quality in 15 shallow wells in rural settlements in the central region of the state of Rondônia, reported a minimum value of 12 NTU and a maximum of 42.32 NTU for turbidity. Furthermore,[23] in an assessment of water quality for human consumption and acute diarrheal diseases in the state of Tocantins, observed a correlation between turbidity greater than 5 NTU and samples with the presence of *Total Coliforms* and *E. coli* in some municipalities in the state.

Specifically, the reported values for the apparent color of the water significantly exceed the maximum permitted limits, indicating water quality that can adversely affect both public health and the environment. The apparent color of the water, illustrated in the chart (Fig. 3) below, shows the comparative values of the wells and the maximum permitted value according to the regulation.

The apparent color of the water, as illustrated, recorded a value of 44.2 for Well 6, which exceeds the maximum limit of 15 (uH). This parameter is crucial because high color in water, usually due to the presence of organic and inorganic materials, can indicate environmental degradation processes. Moreover, high apparent color often signals the need for more complex and costly treatments to make the water suitable for human consumption.

While most wells have low values within acceptable standards, Well 6 stands out with a significantly high value, far exceeding the maximum permitted value (MPV). This discrepancy indicates a potential alteration in the water quality of Well 6, requiring further investigation to identify the underlying causes.

Therefore, the data analysis highlights the importance of regularly monitoring water quality, promptly identifying and addressing any anomalies in test results, and implementing preventive measures to ensure safety and compliance with established water quality standards.

The turbidity of the water, illustrated in the graph in Fig. 4 below, compares the values from the wells with the maximum permitted value according to Ordinance No. 888/2021.

The turbidity recorded a value of 47 for Well 6, significantly exceeding the maximum limit of 5 UNT set by Ordinance No. 888/2021. In contrast, the other wells remained compliant with the current ordinance. Turbidity is caused by the presence of fine suspended particles in the water, which can be of organic origin, such as algae and microorganisms, or inorganic, such as sediments. High turbidity values can affect the aesthetic quality of the water. Authors such as [24] emphasize that water turbidity can be interpreted as a lack of clarity. It is defined by the presence of colloidal material in suspension, such as clay, sludge, organic or inorganic matter, and microscopic organisms.

The presence of turbidity values above the permitted limit, as observed in Well 6, can pose various public health risks. It is also an indirect parameter indicating the quality of water for public supply. According to[25] and[26], turbidity is an indirect parameter that reveals the quality of water for public supply.

Consuming water with high turbidity can increase the risk of gastrointestinal diseases, bacterial and viral infections, and poses a threat to health, especially for vulnerable groups such as children, the elderly, and individuals with compromised immune systems.

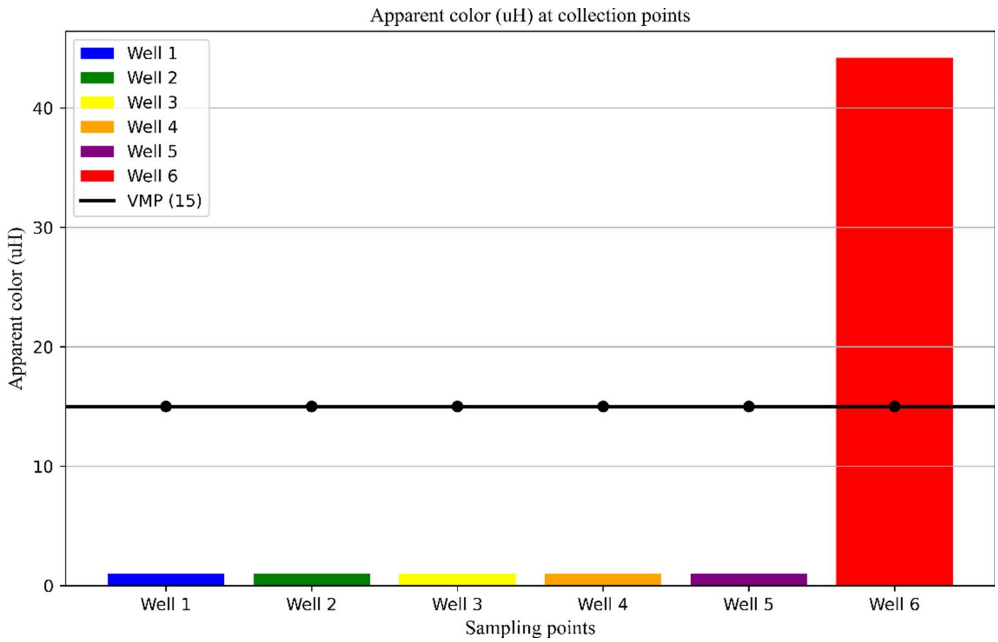

Fig. 3. Source: The Authors (2024).

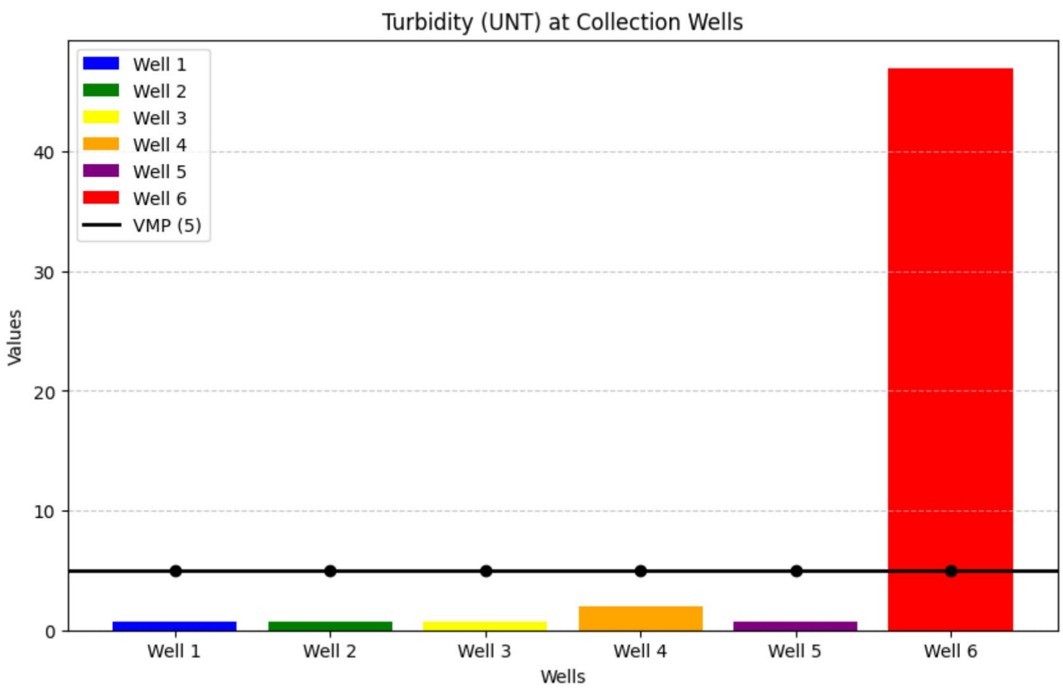

Fig. 4. Source: The Authors (2024).

In the illustration of Fig. 5, we present the four physicochemical parameters in a graph, comparing all the wells.

The graph in Fig. 5 presents a comparison between the values of Total Iron and Manganese measured at different sampling points. On the horizontal axis (X), we have the points where the measurements were taken, while the vertical axis (Y) shows the values of these parameters in milligrams per millilitre (mg/mL). The green line represents the values of Total Iron, and the red line represents the values of Manganese. As both sets of values are identical and overlap on the graph, the green line is positioned underneath the red line.

The values measured at all points remain at zero, indicating that no significant concentrations of Total Iron or Manganese were detected in the collected samples. This means that the water quality at the analysed points is good with respect to these two elements, as there is no relevant presence of Total Iron or Manganese that could

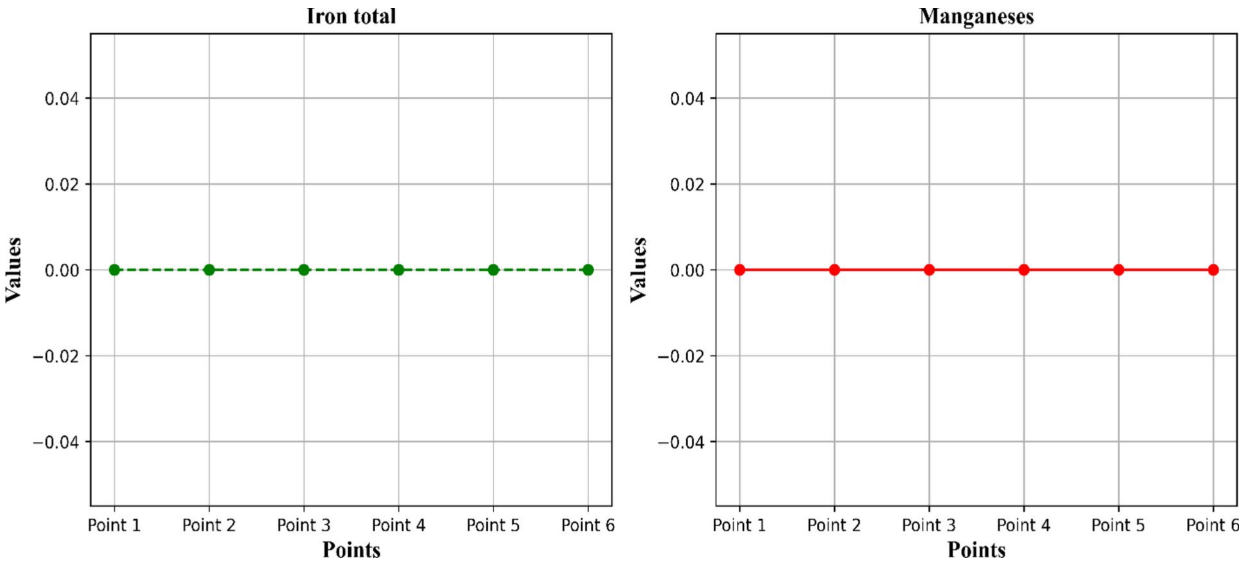

Fig. 5. Graph of sampling point values for Total Iron and Manganese. Source: The Authors (2024).

Parameters	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	MPV
Thermotolerant Coliforms (fecal)	Absent	Absent	Absent	Absent	Absent	**Present**	Pres/Abs
Total Coliforms	Present	Absent	Absent	Absent	Absent	**Present**	Pres/Abs

Table 5. Evaluation of the microbiological parameters of drinking water in the municipality of Manicoré/AM. Note: MPV (*): Maximum Permitted Values for *E. coli* is absent in 100 mL according to Ordinance No. 888/21 Source: The Authors (2024).

indicate contamination or pollution. Therefore, the absence of variation in the values and the fact that the lines remain at zero demonstrate that, at all evaluated points, the water is free from concentrations of these two metals.

Even though the concentrations of iron and manganese were found within the limits imposed by Brazilian legislation, with values of 0.3 mg/L for iron and 0.1 mg/L for manganese, it may be relevant to consider the implications of exceeding these limits for public health. Directive 98/83/EC of the Council of the European Union, which sets standards for drinking water quality in EU countries, adopts stricter limits: 0.2 mg/L for iron and 0.05 mg/L for manganese.

These more restrictive values reflect a preventive approach to the potential health effects of these metals, considering that consuming water with elevated levels of iron and manganese may be associated with issues such as altered taste, water discoloration, and potential health risks from prolonged exposure. Given that Brazilian standards are more permissive, discussing these differences could help to understand the impact of these substances on health and water quality. This comparison with European regulations could provide a basis for considering adjustments in local parameters, especially in contexts where water quality and health safety are priorities[27].

Table 5 presents the results of the microbiological parameters for the 6 analyzed wells.

Well 1 revealed the presence of total coliforms, while Wells 2, 3, 4, and 5 indicated the absence of total coliforms and thermotolerant coliforms. However, Well 6 showed the presence of both total coliforms and thermotolerant coliforms (fecal). The results found in Well 6 do not meet the recommendations of Ordinance No. 888/2021 from the Ministry of Health (MS), which emphasizes the absence of pathogenic agents in water used for human consumption. A possible influence on these results is the proximity of cesspits to the well, which may have led to contamination of the water due to this activity. Research by Rosá et al. 2022[28] and Pinheiro et al. 2023[29] this result is corroborated by the presence of coliform bacteria, which are indicators of water quality and can signal a potential environmental impact resulting from activities around the water body. Since water quality is crucial for public health, inadequate sanitary conditions can turn water into a medium for pathogen proliferation, such as *Escherichia coli*, in addition to other coliforms.

It is important to note that Well 6 is surrounded by households with operational cesspits, which may be sources of pollution. Poor conditions of pipes and water reservoirs could also be contributing factors. Other factors supporting the presence of total coliforms and thermotolerant coliforms include the high levels of apparent color and turbidity in this well. Similar studies in the municipality of Lábrea/AM by[30] and[9] identified the presence of total and thermotolerant coliforms in water intended for human consumption, confirming that this is a public health issue.

Therefore, the non-compliance of these parameters in water from Wells 1 and 6 is concerning, as it suggests that the water does not meet the required quality standards for human consumption, making it potentially unsuitable for this purpose. It is crucial that corrective measures are taken to address this non-compliance, ensuring that the water meets the necessary quality and safety standards to protect public health. This may involve implementing appropriate water treatment measures and conducting continuous monitoring to ensure that quality standards are maintained over time.

The results obtained for well P6 indicate that the high turbidity of the water has a significant impact on the measurement of apparent color. The presence of colloids and particulate matter suspended in the water can absorb light, resulting in elevated and distorted coloration. This interference not only complicates the interpretation of water quality but also raises concerns about potability, as high turbidity levels can be indicative of contamination by microorganisms and unwanted particles. Therefore, it is essential to conduct a careful analysis of the data, considering the relationship between turbidity and apparent color, in order to provide a more accurate assessment of water quality.

Furthermore, when stating that only wells P6 and P1 are affected by problems related to inadequate sewage treatment in urban areas, it is necessary to deepen the discussion, including an evaluation of groundwater levels and local topography. These variables can influence the dynamics of water flow and pollution contamination, making them relevant for understanding the water quality in the analyzed wells. Investigations that consider these aspects will help identify the underlying causes of water quality degradation, contributing to the development of mitigation and control strategies that ensure the potability of water for the inhabitants of the region.

Conclusion

The results of this study highlight the urgent need to establish a continuous monitoring programme and implement improvements to ensure the quality of drinking water in inhabited regions of the Amazon. The detection of total coliforms at Point 1, as well as total and thermotolerant (faecal) coliforms at Point 6, indicates that these wells do not comply with the sanitary requirements defined by Ministry of Health Ordinance No. 888/21. In addition, the parameters related to apparent colour and turbidity at Point 6 showed values significantly above the permissible limits, indicating potential health risks.

Although Points 2, 3, 4, and 5 were in compliance with current legislation regarding microbiological aspects and levels of total iron and manganese, the overall situation suggests that, even in locations where parameters meet the limits, it is essential to maintain regular control. These findings reinforce the importance of a robust water quality surveillance system to reduce contamination risks and protect public health. Therefore, it is necessary to adopt strategies that ensure the safety of the water consumed, promoting both compliance with legal standards and the environmental and sanitary protection of Amazonian communities.

Data availability

Manuscript from the TCC by student Eliezer Lucio Fernandes Lima, Environmental Engineering Course at the Federal University of Amazonas (UFAM). The datasets generated and/or analyzed during the present study are not publicly available due to the recent defense and approval of the course completion work, which is still in the deposit phase in the Institutional Repository of the Federal University of Amazonas (RIU). However, these data may be obtained upon reasonable request to the corresponding author.

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Author contributions
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Declarations

Competing interests
The authors declare no competing interests.

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