

Physicochemical quality of the three most consumed bottled mineral water brands in Moçâmedes, Namibe, Angola

Calidad físico-química de las tres marcas de agua mineral embotellada más consumidas en Moçâmedes, Namibe, Angola

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Abstract

In Moçâmedes, consumption of bottled mineral water is high due to limitations in the public water supply, raising concerns regarding the quality of the brands on sale. This study assessed the physico-chemical quality of the most widely consumed brands of bottled mineral water in the municipality of Moçâmedes, comparing the laboratory results with the limits established by the World Health Organisation and Angolan legislation. A descriptive, cross-sectional study with an analytical-laboratory component was conducted, using questionnaires and physico-chemical analyses of water samples. The parameters assessed included temperature, pH, electrical conductivity, turbidity, residual chlorine, total iron and total hardness. The results demonstrated compliance with health-related standards for most parameters. However, iron concentrations exceeded the WHO aesthetic guideline value (0,3 mg/L) in two brands, whilst residual chlorine (0,18 mg/L) was detected in one sample. The water samples analysed showed low mineralisation and low hardness, indicating relatively protected groundwater sources. Overall, the waters assessed were of adequate physico-chemical quality for human consumption. Periodic monitoring and improvements in labelling practices are recommended.

Keywords: bottled mineral water, water quality, physico-chemical parameters, groundwater, Moçâmedes

Resumen

En Moçâmedes, el consumo de agua mineral embotellada es elevado debido a las limitaciones en el suministro público de agua, lo que genera inquietudes respecto a la calidad de las marcas comercializadas. Este estudio evaluó la calidad físico-química de las marcas de agua mineral embotellada más consumidas en el municipio de Moçâmedes, comparando los resultados de laboratorio con los límites establecidos por la Organización Mundial de la Salud y la legislación angoleña. Se llevó a cabo un estudio descriptivo y transversal, con un componente analítico-laboratorial, utilizando encuestas y análisis físico-químicos de muestras de agua. Los parámetros evaluados incluyeron temperatura, pH, conductividad eléctrica, turbidez, cloro residual, hierro total y dureza total. Los resultados demostraron el cumplimiento de los estándares relacionados con la salud para la mayoría de los parámetros. Sin embargo, las concentraciones de hierro superaron el valor guía estético de la OMS (0,3 mg/L) en dos marcas, mientras que se detectó cloro residual (0,18 mg/L) en una muestra. Las aguas analizadas presentaron baja mineralización y baja dureza, lo que indica fuentes subterráneas relativamente protegidas. En general, las aguas evaluadas presentaron una calidad físico-química adecuada para el consumo humano. Se recomienda un monitoreo periódico y mejoras en las prácticas de etiquetado.

Palabras clave: agua mineral embotellada, calidad del agua, parámetros físico-químicos, agua subterránea, Moçâmedes

1. INTRODUCTION

Bottled drinking water plays an increasingly important role in urban areas where public water supply is irregular or perceived as unreliable. In semi-arid regions of southern Africa, including coastal Angola, bottled natural mineral water is widely consumed as an alternative source of drinking water, making its quality an important public health and water governance issue. In addition to its role as a commercial product, bottled mineral water may also provide indirect information about the groundwater resources exploited for abstraction and bottling (Miguel, 2018; Malheiro, 2019; Umoafia et al., 2023).

The physical and chemical composition of mineral waters is determined by geological formations and mineral dissolution processes during underground circulation. Parameters such as pH, electrical conductivity, iron and hardness vary according to aquifer characteristics and groundwater residence time (Bachir et al., 2021; Chintali et al., 2023; Gitau et al., 2023; Ogana et al., 2024). Therefore, physicochemical analyses represent an important tool for the environmental characterisation of groundwater resources.

The groundwater aquifers exploited for bottled mineral water production in the municipality of Moçâmedes are influenced by dynamic hydrogeological processes, including groundwater recharge variability, mineral dissolution, residence time and water-rock interaction. These factors directly affect water composition and may lead to temporal variations in parameters such as iron concentration, conductivity and pH. Understanding these hydrogeochemical dynamics is essential for groundwater protection, environmental monitoring and sustainable water resource management in arid and semi-arid regions such as Namibe Province.

In Angola, discrepancies between label information and laboratory analyses have highlighted weaknesses in bottled mineral water monitoring systems (Fernandes, 2014). Similar studies in African countries reported variations in pH, turbidity, iron and trace metals associated with geological and operational factors (Odiana & Edosomwan, 2019; Mussa & Kaleem, 2022).

The World Health Organisation (2022) established limits for essential physicochemical parameters to protect health and preserve water quality. In Angola, Law No. 6/02 and Presidential Decree No. 261/11 (2011) establish legal criteria for water exploitation and commercialisation.

In Moçâmedes, despite the increasing exploitation of mineral water, several brands present incomplete labelling regarding physicochemical parameters. Consumer and seller surveys also indicate that regular laboratory analyses are not systematically conducted, limiting environmental assessment and groundwater management.

Beyond its commercial importance, bottled mineral water may serve as an indicator of groundwater quality. However, no published studies have specifically evaluated undeclared physicochemical parameters of the most consumed bottled mineral water brands in Moçâmedes, representing an important scientific gap.

Thus, the following research question was formulated: do the most consumed mineral water brands in Moçâmedes have physicochemical parameters compatible with WHO (2022) and Angolan legislation?

The overall objective of this study was to assess the physicochemical quality of the most consumed mineral water brands in Moçâmedes as an indicator of exploited groundwater quality. The specific objectives were: (i) identify the most consumed brands; (ii) determine undeclared physicochemical parameters; (iii) compare results with WHO (2022) and Presidential Decree No. 261/11 standards; and (iv) assess potential non-conformities and implications for environmental management.

Given the increasing consumption of bottled mineral water in Moçâmedes and the absence of published studies assessing non-labelled physicochemical parameters of the most consumed brands, this study contributes to understanding groundwater quality and supports environmental monitoring and sustainable water resource management in Angola. Therefore, this study aimed to assess the physicochemical quality of the most consumed bottled mineral water brands in Moçâmedes and evaluate their compliance with WHO guidelines and Angolan legislation.

2. MATERIALS AND METHODS

2.1. Type of Study

This is a descriptive, cross-sectional study with an analytical-laboratory component, developed in two stages: application of surveys to identify the most consumed brands of mineral water and physical-chemical analysis of samples, with the aim of assessing the quality of bottled mineral water as an indicator of the quality of groundwater resources in the municipality of Moçâmedes.

2.2. Study Area

The study was conducted in the municipality of Moçâmedes, Namibe Province, located in southern Angola, with geographical coordinates (15° 11' 43" S and 12° 09' 03" E). The area is characterised by an arid to semi-arid climate and limitations in public water supply (Figure 1).

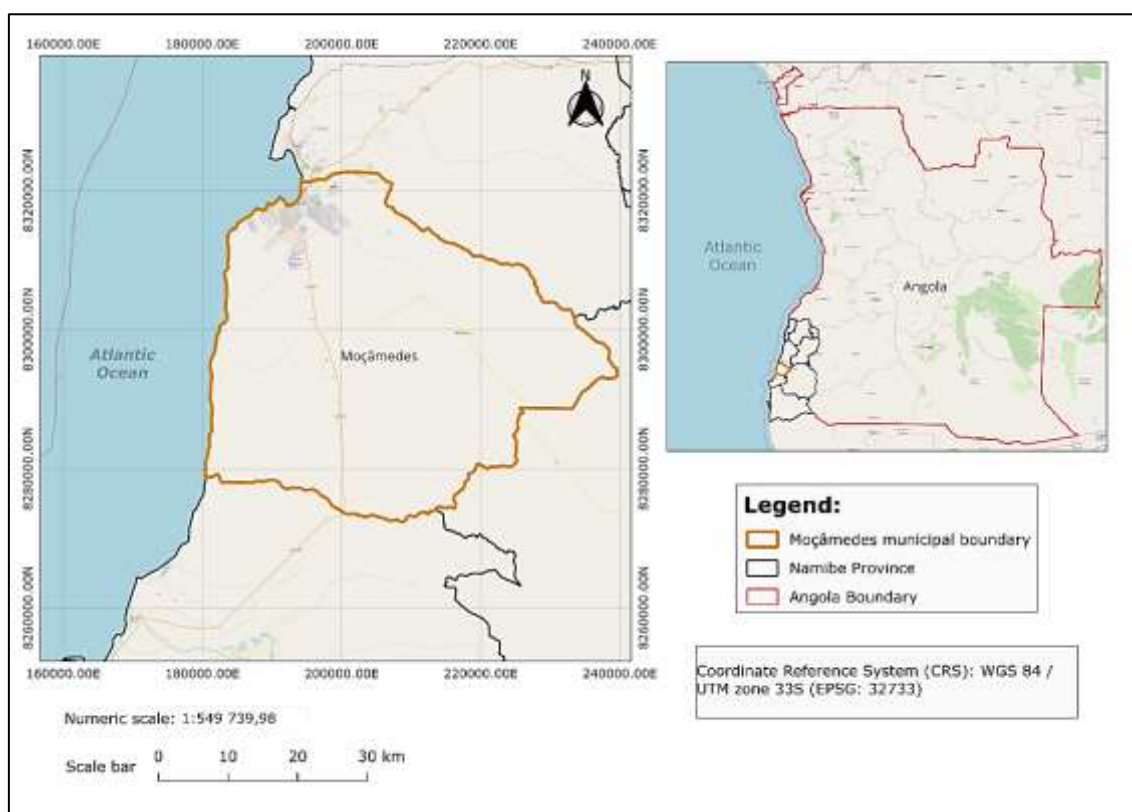


Figure 1. Study area, municipality of Moçâmedes. Source: Prepared using QGIS v. 3.40.9 (Authors).

2.3. Phase I - Field surveys

A structured survey was conducted among 71 consumers and 29 sellers/suppliers, totalling 100 respondents, to identify the most consumed mineral water brands in Moçâmedes. The results revealed three brands with the highest market share, which were selected for laboratory analysis. A non-probabilistic convenience sampling approach was used, based on the accessibility and availability of respondents during data collection. Although this limits statistical generalisation, the survey provided sufficient information to identify the most commercialised bottled water brands in the municipality.

2.4. Phase II – Water sampling

For each of the three identified brands, ten sealed bottles of mineral water were purchased from different retail outlets in the Municipality of Moçâmedes, namely Shoprite, Nosso Super and the 5th of April Market, totaling 30 samples, which were transported to the laboratory on the same day. The commercial brands analyzed corresponded to Chela, Preciosa and Pura, obtained in a distributed manner across all points of sale according to commercial availability at the time of collection, with no fixed association established between specific brands and individual retail outlets.

Ten bottles of each brand were purchased to ensure sample representativeness and analytical reliability. Five bottles were randomly selected for physicochemical analyses using simple random sampling procedures, while the remaining bottles were preserved as reserve and control samples to confirm analytical consistency and permit repeat analyses if necessary.

For the purposes of analysis and presentation of results, the brands were coded as Water 1, Water 2 and Water 3, respectively (Table 1).

Table 1. Identification of bottled mineral water samples analyzed

Code	Commercial brand	Type of water	Package volume	Place of purchase
Water 1	Chela	Natural mineral water	1.5 L	Local retail outlets*
Water 2	Preciosa	Natural mineral water	500 mL	Local retail outlets*
Water 3	Pura	Natural mineral water	500 mL	Local retail outlets*

* Samples were purchased across multiple retail outlets (Shoprite, Nosso Super, and the 5th of April Market) based on availability.

For the physicochemical analyses, five bottles per brand were randomly selected, while the remaining bottles were kept as control and reserve samples, in accordance with good laboratory practices. The results correspond to the arithmetic mean of the five individual measurements performed for each physicochemical parameter.

All analysed bottles were within their expiration dates and were visually inspected to ensure package integrity. During transportation and storage prior to analysis, the samples were maintained under appropriate environmental conditions, protected from direct sunlight and excessive heat, in order to avoid alterations in physicochemical characteristics.

2.5. Laboratory Procedures

Physical-chemical analyses were carried out at the Namibe Public Water and Sanitation Company (EPASN) laboratory, following standard procedures recommended by WHO (2022) and *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, & WEF. (2017). The following parameters were determined: temperature, pH, electrical conductivity, turbidity, residual chlorine, total iron, and total hardness. All analyses were

performed using appropriate methods for each parameter, ensuring reliability and reproducibility.

Temperature and pH were measured by potentiometry, electrical conductivity by electrometry, turbidity by nephelometry, total hardness by titration, and residual chlorine and iron by colorimetry. The obtained values were compared with WHO (2022) guidelines and current Angolan legislation.

3. RESULTS

The results of this study are presented in two parts: (i) results of surveys conducted with consumers, sellers, and health agents; and (ii) results of physical-chemical analyses of the three selected brands of mineral water.

3.1. Survey results

The results of the surveys conducted among consumers indicated that three brands account for most of the mineral water consumption in the municipality of Moçâmedes, with Water 1 (45 %) in first place, followed by Water 2 (27,27 %) and Water 3 (18,18 %) (Figure 2).

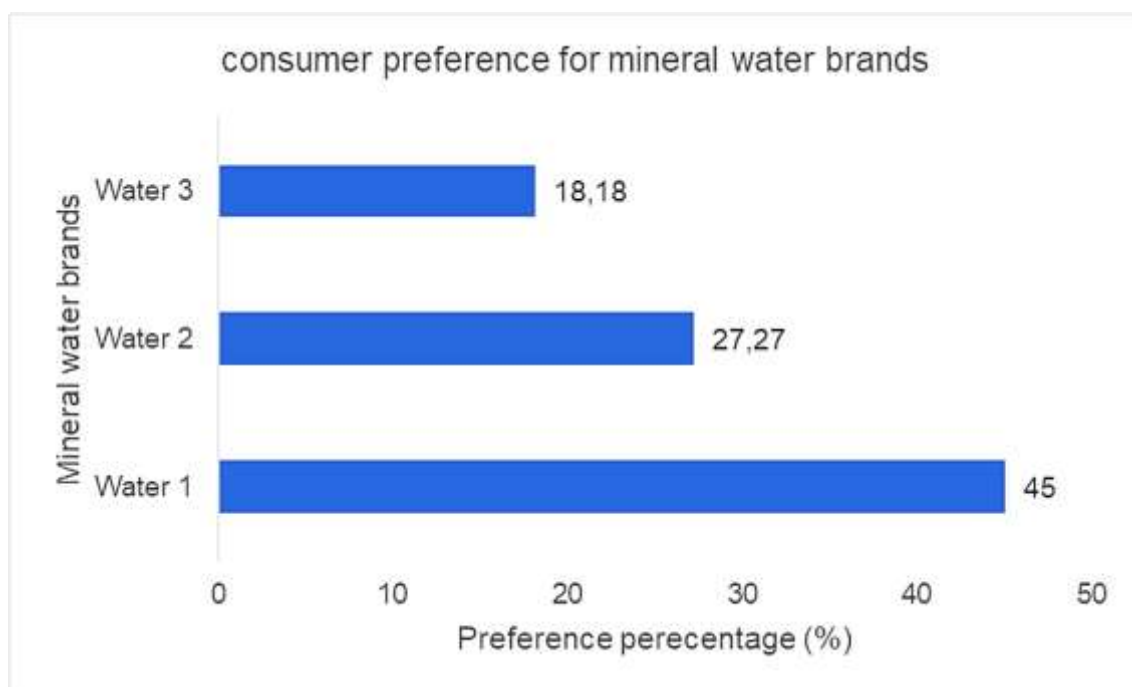


Figure 2. Consumer preference for mineral water brands.

According to sellers and suppliers, 12 brands of mineral water were identified as being sold in the municipality. The best sellers were Water 1 (40 %) and Water 2 (40 %), while Water 3 accounted for 10 % of sales; the other brands together accounted for 10 % of the volume sold.

With regard to laboratory analyses, it was found that 80 % of suppliers do not carry out analyses of the mineral water sold, while only 20 % stated that they carry out external analyses, mainly in laboratories located in Luanda and South Africa.

3.2. Results of laboratory analyses

The results of the physical-chemical analyses of the bottled mineral water samples are presented in Table 2. The values presented correspond to the average of the five samples analysed for each brand.

Table 2. Physical-chemical results for the three brands of mineral water

Parameter	Water 1	Water 2	Water 3	WHO (2022) indicator	Presidential No. 261/11
Temperature (°C)	26,1	26,0	26,5	25 °C	25°C
pH (Sorensen)	8,27	8,41	8,74	6,0 - 9,0	5,5 - 9,0
Conductivity(μS/cm)	18,19	11,80	71,9	≤ 1000	1000
Turbidity (NTU)	0,00	0,00	0,00	≤ 5	---
Residual Chlorine(mg/L)	0,0	0,18	0,0	≤ 5	---
Iron (mg/L)	0,08	0,86	1,34	0.3 (aesthetic) /2.0 (health)	2,0
Hardness (mg/L)	30	30	30	≤ 500	---

Note: (---) The limit values for turbidity residual chlorine and hardness are not specified in Presidential Decree No. 261/11.

The WHO (2022) aesthetic guideline value of 0,3 mg/L for iron was used as the main reference, as exceedances may affect taste, colour, and consumer acceptability of bottled water, even without direct health risks.

Residual chlorine was detected only in Water 2 (0,18 mg/L). Although not a health concern, its presence is unusual in natural mineral water and may indicate post-abstraction disinfection or inconsistencies in product classification.

The average pH values ranged from 8,27 to 8,74 (Figure 3). Electrical conductivity values ranged from 11,8 μS/cm to 71,9 μS/cm (Figure 4). Iron concentrations ranged from 0,08 mg/L to 1,34 mg/L (Figure 5).

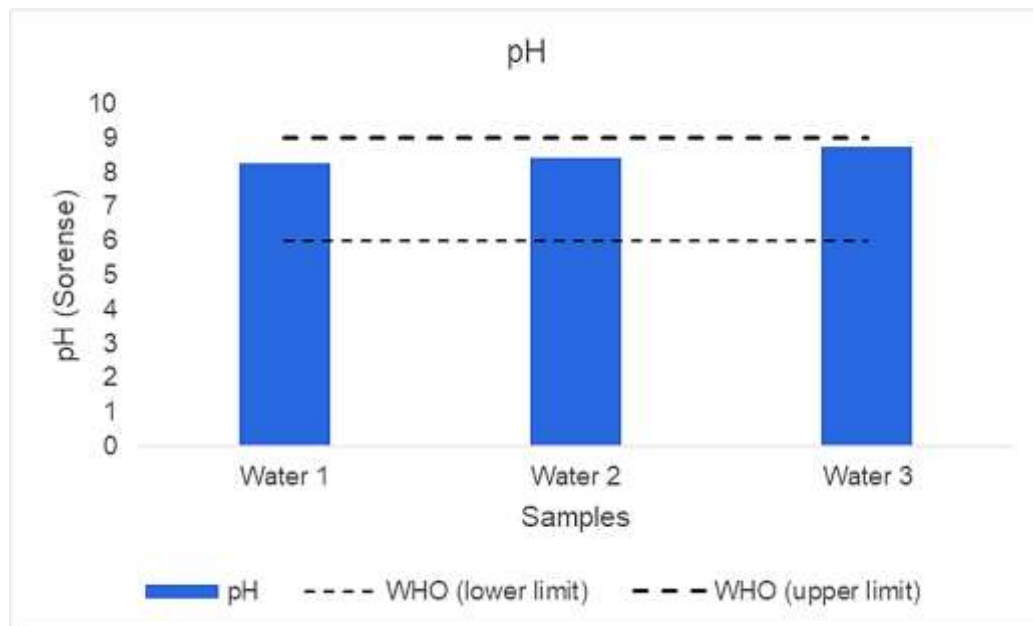


Figure 1. pH values of the three brands of mineral water.

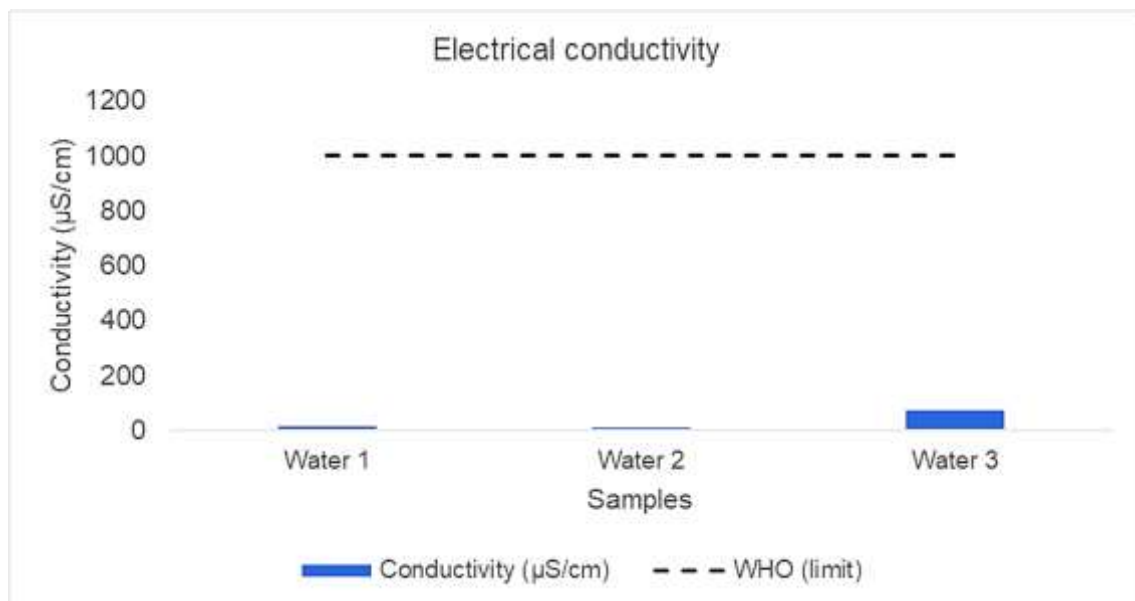


Figure 4. Electrical conductivity of the three brands of mineral water.

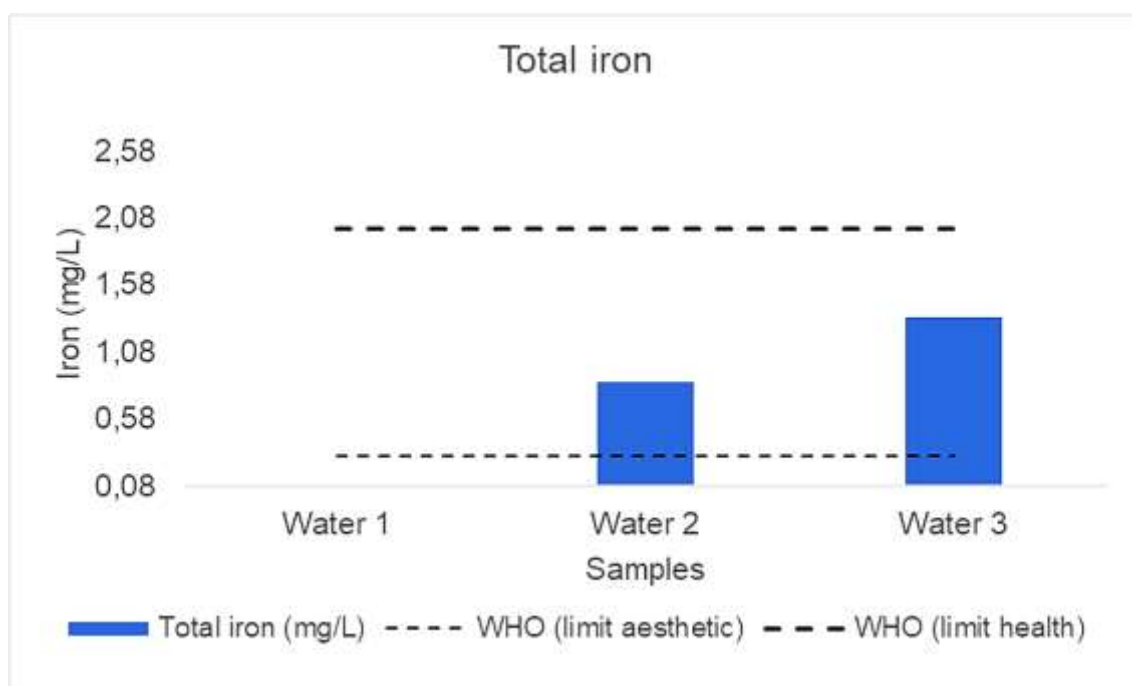


Figure 5. Iron (mg/L) in the three brands of mineral water.

Physical-chemical assessments show variation between brands in the parameters measured.

4. DISCUSSION

The physicochemical assessment provided important information regarding the quality of the most consumed bottled mineral water brands in Moçâmedes, allowing identification of hydrogeochemical characteristics associated with exploited groundwater aquifers and their implications for environmental monitoring and public health.

The selection of the bottled mineral water brands analysed was based on survey results conducted in the municipality of Moçâmedes, which identified the three brands with the highest representation in the local market. Their selection reflects consumption patterns associated with market availability, consumer confidence and individual preferences.

Overall, the results indicate that the most consumed bottled mineral water brands in Moçâmedes present physicochemical characteristics compatible with the standards established by WHO (2022) and Angolan legislation, particularly regarding limits associated with risks to human health. These findings suggest favourable groundwater conditions and adequate collection and bottling practices.

The average pH values remained within the recommended range, indicating appropriate acid-base balance and chemical stability of the analysed waters.

Similar findings have been reported in studies conducted in different African countries, where bottled mineral waters also presented pH values within recommended limits, generally associated with aquifer geological composition and the absence of acid contamination processes (Odiana & Edosomwan, 2019; Bachir et al., 2021).

Electrical conductivity showed low average values, characteristic of low-mineralised waters and consistent with the low total hardness observed. These findings suggest limited mineral dissolution during groundwater circulation, a common characteristic of aquifers with reduced water-rock interaction. Similar studies conducted in comparable geological settings have associated low conductivity and hardness values with relatively protected aquifers (Molefe et al., 2020).

The zero-turbidity observed in all analysed brands indicates the absence of suspended particles, suggesting effective natural aquifer protection and adequate collection and bottling procedures. Similar findings have been described in African studies, where low turbidity values were associated with groundwater presenting reduced influence from surface contamination sources (Mussa & Kaleem, 2022).

Regarding total iron, two brands presented average concentrations above the WHO aesthetic guideline value, although all concentrations remained below the maximum permissible limit associated with health risks. Iron occurrence in groundwater is commonly associated with natural dissolution of ferrous minerals and does not necessarily indicate anthropogenic contamination. Similar findings have been reported in African regions where elevated iron concentrations were associated with geological characteristics of exploited aquifers (Odiana & Edosomwan, 2019; Abel et al., 2024). Variations in iron concentration among brands may reflect differences in lithology, groundwater residence time and hydrogeochemical conditions.

One of the most relevant findings of this study was the detection of residual chlorine in Water 2. According to international standards, natural mineral water should not undergo disinfection treatments capable of altering its original physicochemical composition. Therefore, the presence of residual chlorine may indicate post-abstraction treatment processes, possible inconsistencies in labelling, or non-compliance with the legal definition of natural mineral water. Although the detected concentration does not represent an immediate health concern, this finding raises important regulatory and environmental management questions regarding monitoring and classification of bottled waters commercialised within the Angolan

market. Additional confirmatory analyses and regulatory inspections are recommended to clarify the origin of the detected chlorine.

From an environmental perspective, iron concentrations above the recommended aesthetic limit reinforce the need for continuous groundwater quality monitoring, since variations in aquifer geochemical conditions or abstraction processes may influence its mobilisation. In addition, elevated iron concentrations may affect consumer acceptance, highlighting the importance of adequate declaration of physicochemical parameters on product labels.

Despite compliance with most potability standards, incomplete labelling observed in some brands represents an important limitation regarding transparency and consumer information.

The results reinforce the importance of physicochemical assessment of bottled mineral waters as a tool for evaluating suitability for consumption and supporting groundwater monitoring and sustainable water management in Moçâmedes.

5. STUDY LIMITATIONS

One of the main limitations of this study was the absence of microbiological analyses, which are also essential for a comprehensive assessment of bottled mineral water quality. Furthermore, the analyses were conducted during a single sampling period, which did not allow the evaluation of possible seasonal variations in the physicochemical composition of the analysed waters.

In addition, the relatively limited number of analysed samples may restrict broader generalisation of the results to other bottled mineral water brands commercialised in the region.

Despite these limitations, the study provides relevant information regarding the physicochemical quality of the most consumed bottled mineral water brands in the municipality of Moçâmedes and contributes to strengthening environmental monitoring and sustainable groundwater management in the region.

6. CONCLUSIONS

- The present study evaluated the physicochemical quality of the three most consumed bottled mineral water brands in the municipality of Moçâmedes, demonstrating overall compliance with the limits established by the World Health Organisation and Angolan legislation for human consumption.

- The results revealed low-mineralised waters associated with relatively protected aquifers and limited water-rock interaction. However, elevated iron concentrations identified in two brands highlight the influence of local hydrogeochemical conditions and reinforce the need for continuous monitoring of exploited groundwater resources.
- The detection of residual chlorine in Water 2 represents a relevant finding, as it is incompatible with the expected characteristics of natural mineral water, suggesting possible post-abstraction treatment processes or inconsistencies in the commercial classification of the product.
- Beyond its public health relevance, the study reinforces the importance of physicochemical assessment of bottled waters as a tool for environmental monitoring and sustainable groundwater resource management in arid and semi-arid regions of Angola.
- Strengthening regulatory inspection, improving labelling practices, and conducting future studies including microbiological analyses and seasonal monitoring of aquifer hydrogeochemical dynamics are recommended.

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The authors also pay posthumous tribute to Professor Agostinho Cachapa, whose scientific contribution, academic dedication and guidance were instrumental in the design and development of this work. His academic and human legacy remains a reference and inspiration for the scientific community.

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Additional Information

Conflict of interest

The authors declare that there are no conflicts of interest.

Author Contributions

AFCM: Contributed to the conception of the study, application of questionnaires, sample collection, data organization, discussion of results, and manuscript writing. **AFC:** Contributed to the scientific guidance of the study, definition of the methodology, and critical review of the manuscript. **MCA:** Contributed to the analysis and interpretation of physicochemical data, final review of the manuscript, and article submission. **WEDH:** Contributed to the georeferencing of the study area, preparation of the map in QGIS, and environmental interpretation of the results. **AMB:** Contribution to the analysis, organization, interpretation of results, and

manuscript review. **IFGB**: Contributed to data analysis, figure preparation, and manuscript review. **TSIM**: Contributed to the environmental interpretation of results and manuscript review. **JJM**: Contributed to the discussion of results and environmental framing.

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