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Physical, Chemical And Bacteriological Indicators Of Well Water Around A Necropolis Located In The Urban Area Of The Municipality Of Paraíso Do Tocantins

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Abstract

During the months of September 2023 to July 2024, groundwater samples were collected at 10 sampling sites, distributed in the Sector Oeste neighborhood, in the city of Paraíso do Tocantins, state of Tocantins, with the aim of assessing the quality of groundwater captured in tube wells potentially used for human consumption. For all the groundwater samples, the physicochemical parameters ammonia, chloride, apparent color, hardness, nitrate, nitrite, pH, turbidity and microbiological total and thermotolerant coliforms were analyzed. Based on these results and in order to better understand the physicochemical behavior of these waters, principal component analysis (PCA) was used to carry out a more complete evaluation of the original data. The physicochemical and microbiological parameters assessed in the groundwater collected showed that 90% of the wells had pH values below those recommended in Ordinance GM/MS No. 888/2021 and the presence of total and thermotolerant coliforms in all the water samples from the wells analyzed, which is in disagreement with the legislation. In addition, the PCA explained 49.84% of the total variance of the data, making it possible to assess the degree of similarity between the samples. It is important to have more reliable monitoring and assessment of groundwater in cemetery areas and prior knowledge of the chemical composition of this water, as this is the only way to assess whether any parameter is altered, even if its concentration is equal to or lower than that considered naturally occurring by current legislation.

Key Word*: Public health; Urban macrocephaly; Multivariate analysis; Groundwater.*

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I. Introduction

Water is essential for the survival of all living beings on planet Earth, and it is indispensable for human beings [1]. It is a vital substance for maintaining life, necessary at all stages of human development, participating in digestion, blood circulation, respiration, urinary excretion and perspiration [2]. It is also indispensable for commerce and industry, being used in various stages of production processes [3]. However, despite covering 71% of the earth's surface, only 0.3% of water is available to meet human needs [4].

Water is an abundant natural resource on the planet, but 97.5% of the world's water is salty and not suitable for direct human consumption or even for irrigating crops. The remaining 2.5% is fresh water, but 69% of this water is difficult to access as it is concentrated in glaciers, 30% comprises groundwater in aquifers and 1% is found in rivers [5]. Natural groundwater has varied physical and chemical properties, such as color, turbidity, temperature and electrical conductivity, which can be influenced by its geolocation [1].

In the urban context, the physical and chemical properties of groundwater can be altered, since urban macrocephaly impacts the environment with various problems such as degradation of water resources and soil composition, changes in water and soil quality [6]. In this scenario, shallow wells, usually drilled manually, are used to obtain groundwater and are an option for consuming water from underground reserves [7]. According to [8], drilling wells that are not subject to technical criteria and site studies can put the quality of groundwater at risk, as it can lead to a connection between shallower waters, which are more susceptible to contamination, and deeper waters, and also the health of the population that consumes this water.

The quality of the water is influenced by the height of the shallow well, since depths of less than 6 (six) meters have a chemical composition that changes more easily in relation to the type of soil in which they are stored, which can make them of poor quality if they contain dissolved or precipitated minerals, and they are susceptible to anthropogenic alterations caused by the concentration of nitrate, total and thermotolerant coliforms [9].

Due to a lack of urban planning, in some places these wells are drilled close to areas with a high potential for soil and surface and groundwater contamination, such as necropolises, for example. Necropolises or cemeteries are developments located in an uncovered area, with semi-buried tombs. Inhumation is the usual form of burial, consisting of burying or burying bodies directly in the ground, allowing the bodies to be transformed and disintegrated in accordance with public hygiene requirements [10]. This condition is easy to decompose due to the body's contact with the ground; however, it occupies large areas and makes it possible to contaminate the ground and underground and surface water [9], [11].

According to [10], traditional cemeteries are potential sources of soil and water pollution due to the presence of necrochorume, a compound released during the putrefaction of bodies, especially in the first year of burial. According to the authors, necrochorume is a cloudy gray-brown liquid with a viscosity higher than that of water. Its composition is estimated to be between 70% and 74% water, 30% mineral salts and 10% organic substances, two of which are highly toxic: putrescine ($C_4H_{12}N_2$) and cadaverine ($C_5H_{14}N_2$). The risks to the environment are caused by contamination of the soil and groundwater by substances and microorganisms that make up necrochorume in the process of percolation from the unsaturated zone of the soil to the free aquifer [12].

Continuous monitoring of water quality using physical, chemical and microbiological parameters is of great importance for environmental balance and the promotion of public health [13], [14], [15]. The microbiological and physical-chemical parameters determine the potability characteristics required for human consumption, and these parameters are regulated by norms and standards defined in Ministry of Health ordinances [4]. The complexity of the parameters monitored reflects the main characteristics of the water, which must be in accordance with Ordinance No. 888 of May 4, 2021 of the Ministry of Health, which sets out the norms and standards for the potability of water intended for human consumption [16]. Therefore, for water to be considered potable, it must meet the standards for physical-chemical, microbiological and organoleptic parameters [17].

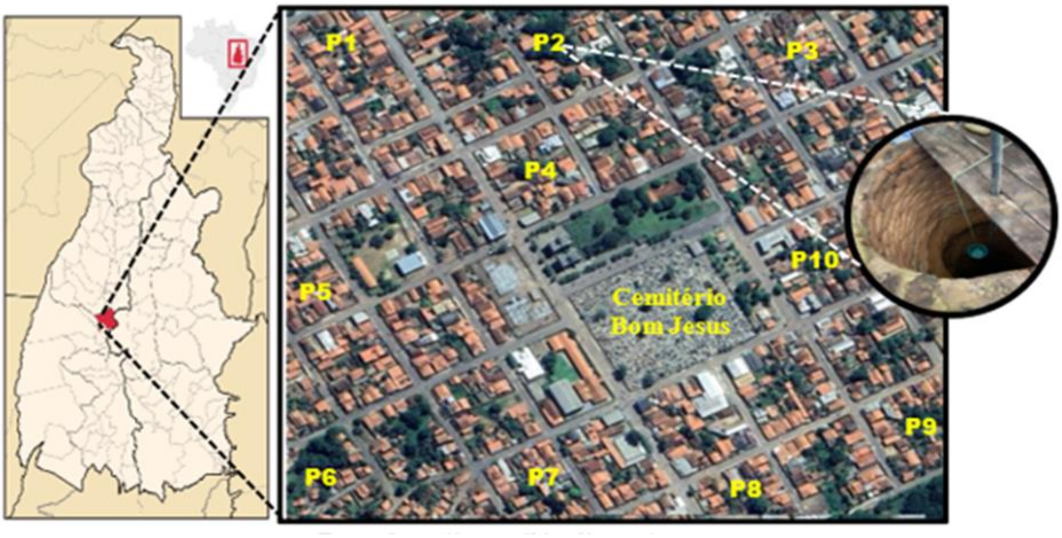
When water is not properly treated, micro-organisms can proliferate, leading to the emergence of a number of serious water-borne diseases that reach groundwater and subsequently water distribution systems [4]. In terms of public health risks, groundwater and surface water with altered quality can cause waterborne diseases (amoebiasis, giardiasis, gastroenteritis, typhoid fever, infectious hepatitis and cholera) in the population that uses these resources, caused by viruses, bacteria and protozoa [12]. Thus, monitoring groundwater is indispensable for determining whether it is safe to consume, as far as contamination of water for human use is concerned [18].

Therefore, given the importance of the potability of water intended for human consumption, the aim of this study was to evaluate possible indicators of physical-chemical and bacteriological contamination of groundwater from artesian wells in the Bom Jesus cemetery, located in the urban area of the municipality of Paraíso do Tocantins.

II. Material And Methods

This is a cross-sectional quantitative study, in which data was used to assess the quality of the water, using physical-chemical and microbiological parameters [19]. Thus, monthly water samples were collected from 10 (ten) wells (A, B, C, D, E, F, G, H, I and J), within a radius of 500 meters, around the Bom Jesus cemetery, located in the Sector Oeste neighborhood, in the city of Paraíso do Tocantins, state of Tocantins (figure 1), from September 2023 to July 2024.

Figure 1 - Location of the city of Paraíso, site and one of the collection points.



Source: Authors, (2024)

The procedures adopted for collecting and transporting the samples followed the National Guide for Collecting and Preserving Samples from the National Water Agency and São Paulo State Environmental Company [19]. The identified samples were packed in a 4 ºC thermal box and transported to the Sanitation Laboratory of the Federal Institute of Education, Science and Technology of Tocantins - Paraíso do Tocantins Campus for physical-chemical and microbiological analysis. The analyses were carried out in triplicates and completed within a 24-hour period, from the moment the water samples were collected.

The physicochemical tests - ammonia, chloride, apparent color, hardness, nitrate, nitrite, pH, turbidity and microbiological total and thermotolerant coliforms - adopted the methodology recommended in the Standard Methods for the Examination for Water and Wastewater [20]. The microbiological analyses were carried out qualitatively through the absence or presence of coliforms, using the Colilert enzymatic chromogenic substrate technique, as current legislation recommends the absence of these microorganisms in the water samples analyzed.

The analysis and interpretation of the physicochemical and bacteriological results were compared with the existing legislation in Ordinance No. 888 of May 4, 2021 of the Ministry of Health [17]. In order to check whether there was a significant difference between the results, ANOVA analysis of variance was applied and Tukey's test was applied between the means of the response variables at a 5% significance level, using the SISVAR program version 5.6 [21]. Principal Component Analysis (PCA) assessed the interrelationship between the data and the treatments according to similarity. The PCA analysis was carried out using the PAST software [22].

III. Result And Discussion

In addition to drinking water, water for human consumption is also used for personal hygiene, food preparation and production, regardless of its origin. Thus, for water to be considered potable, it must meet the standards established by Ordinance GM/MS No. 888, of May 4, 2021 (table 1) for physical, chemical and microbiological parameters, which specifies limits for the parameters Ammonia (mg.L^{-1}), Chloride (mg.L^{-1}), Color (uH), Hardness (mg.L^{-1}), Nitrate (mg.L^{-1}), Nitrite (mg.L^{-1}), pH, Turbidity (uT), Total Coliforms (NMP.100 mL^{-1}) and Thermotolerant Coliforms (NMP.100 mL^{-1})

Table 3. Reference values in Ordinance No. 888/2021MS.

Parameters	GM/MS Ordinance No. 888, of May 4, 2021
Ammonia (mg. L^{-1})	1,2 mg. L^{-1}
Chloride (mg. L^{-1})	250 mg. L^{-1}
Color (uH)	15 uH
Hardness (mg. L^{-1})	300 mg. L^{-1}
Nitrate (mg. L^{-1})	10 mg. L^{-1}
Nitrite (mg. L^{-1})	1 mg. L^{-1}
pH	6,0 a 9,0
Turbidity (uT)	5 uT
Total coliforms (NMP.100 mL^{-1})	Absence in 100 mL
Thermotolerant Coliforms (NMP.100 mL^{-1})	Absence in 100 mL

Source: Authors, (2024)

The results of the physico-chemical analysis of the water samples collected from the wells around Bom Jesus cemetery are shown in Table 2 and the microbiological analysis in Table 3.

Table 2. Physical-chemical analyses.

Well	Ammonia (mg. L^{-1})	Chloride (mg. L^{-1})	Color (uH)	Hardness (mg. L^{-1})	Nitrate ((mg. L^{-1})	Nitrite (mg. L^{-1})	pH	Turbidity (uT)
P1	$0,03^{B}\pm0,01$	$18,88^{H}\pm4,16$	$8,24^{D}\pm3,14$	$9,60^{E}\pm4,81$	$0,83^{F}\pm0,10$	$0,62^{C}\pm0,28$	$5,67^{D}\pm0,54$	$1,10^{A}\pm0,28$
P2	$0,02^{A}\pm0,01$	$18,33^{G}\pm3,65$	$8,47^{F}\pm2,67$	$9,26^{C}\pm5,72$	$0,84^{G}\pm0,08$	$0,63^{D}\pm0,22$	$5,50^{A}\pm0,53$	$1,28^{F}\pm0,39$
P3	$0,02^{A}\pm0,01$	$18,12^{D}\pm3,76$	$8,69^{G}\pm3,09$	$7,58^{A}\pm3,98$	$0,88^{I}\pm0,10$	$0,6^{7F}\pm0,28$	$5,76^{H}\pm0,41$	$1,21^{C}\pm0,31$
P4	$0,02^{B}\pm0,01$	$18,32^{F}\pm3,30$	$8,74^{H}\pm2,57$	$10,71^{F}\pm5,53$	$0,79^{A}\pm0,08$	$0,67^{G}\pm0,26$	$5,71^{E}\pm0,58$	$1,31^{H}\pm0,34$
P5	$0,02^{A}\pm0,01$	$17,16^{B}\pm3,67$	$7,95^{C}\pm3,19$	$13,34^{J}\pm4,83$	$0,86^{H}\pm0,10$	$0,61^{B}\pm0,26$	$5,74^{G}\pm0,57$	$1,18^{B}\pm0,33$
P6	$0,02^{A}\pm0,01$	$18,27^{E}\pm4,38$	$8,24^{D}\pm3,33$	$8,53^{B}\pm4,79$	$0,82^{E}\pm0,08$	$0,64^{E}\pm0,33$	$5,72^{F}\pm0,31$	$1,23^{D}\pm0,29$
P7	$0,02^{A}\pm0,01$	$19,27^{J}\pm3,46$	$9,04^{I}\pm2,88$	$10,78^{G}\pm6,31$	$0,82^{D}\pm0,09$	$0,30^{D}\pm0,19$	$5,61^{B}\pm0,53$	$1,30^{G}\pm0,35$
P8	$0,02^{A}\pm0,01$	$19,22^{I}\pm4,48$	$7,02^{B}\pm2,53$	$11,83^{H}\pm4,79$	$0,81^{C}\pm0,11$	$0,74^{H}\pm0,27$	$5,85^{I}\pm0,53$	$1,27^{E}\pm0,32$
P9	$0,02^{A}\pm0,01$	$16,83^{A}\pm3,81$	$6,25^{A}\pm2,04$	$9,34^{D}\pm6,40$	$0,80^{B}\pm0,07$	$0,67^{F}\pm0,24$	$5,62^{C}\pm0,47$	$1,34^{J}\pm0,35$
P10	$0,03^{B}\pm0,01$	$17,56^{C}\pm4,05$	$8,32^{E}\pm2,23$	$12,83^{I}\pm3,70$	$0,86^{H}\pm0,08$	$0,54^{A}\pm0,20$	$6,13^{J}\pm0,45$	$1,34^{I}\pm0,32$

Different capital letters in the columns indicate a statistical difference using the Tukey test (P<0.05).
Source: Authors, (2024).

Table 3. Microbiological analysis.

Well	Total coliforms (NMP.100 mL^{-1})	Thermotolerant Coliforms (NMP.100 mL^{-1})
P1	presence	presence
P2	presence	presence

P3	presence	presence
P4	presence	presence
P5	presence	presence
P6	presence	presence
P7	presence	presence
P8	presence	presence
P9	presence	presence
P10	presence	presence

Source: Authors, (2024).

According to Table 2, there were significant differences ($p< 0.05$) between the physicochemical parameters in all the wells analyzed. These differences may be associated with the age, type and depth of the well, the lining and age of the pit or drains, the slope of the soil, the press, mechanical workshops, car washes without an effluent treatment system, and the absence of a sewage system in the neighborhood where the physicochemical parameters were collected. In addition, [23], who carried out a physicochemical and microbiological assessment of water in residential wells in the municipality of Laranjal do Jari, Amapá, also found dispersion in the results of the physicochemical parameters at the collection points, due to the depths, distances from the wells to the pits, the depth of the pits and the dumping of domestic sewage directly into the ground. Similarly, [24] and [25] emphasize that soil characteristics, geological formation and biological components can cause changes in the physical and chemical parameters of surface and groundwater.

Table 2 also shows that the physical-chemical parameters ammonia, chloride, apparent color, hardness, nitrate and turbidity were in accordance with GM/MS Ordinance No. 888/2021. Wells 1 to 9 (90%) showed values for the pH parameter ranging from 5.67 to 6.13, in disagreement with this legislation. According to [26], groundwater with an acid pH may be an indication of contamination of tube wells by cesspits and domestic sewage. [16] Oliveira et al (2023), analyzing the quality of water for human consumption in rural communities in the southwest of the Amazon, found slightly acidic pH values in 45.83% of the wells analyzed, due to dissolved carbon dioxide, soil leaching processes, high concentrations of dissolved organic matter, promoting a decrease in the pH of groundwater and surface water, causing a change in the taste of the water, corrosion of water distribution systems and leaching of metals. Therefore, in the tropical climate of the northern region, the degradation of organic matter is more intense in the anaerobic phase, favoring the production of organic acids and, consequently, a more acidic pH [23]. According to [4] acidic pH values can be attributed to the geochemical characteristics of the region's soils due to the aluminum and iron characteristic of leached environments with high temperatures and precipitation. Water with high acidity can cause demineralization of the teeth and problems with the digestive system [27].

The results obtained for the biological determinations showed the presence of total and thermotolerant coliforms, indicating fecal pollution of the water and potentially exposing the population to water-borne diseases, which is not permitted under GM/MS Ordinance No. 888/2021. This contamination may be related to other factors, not just proximity to the cemetery. Among these factors, we can consider the time the well was built, the high density of occupation of the area, combined with the lack of sanitary sewage and proximity to septic tanks [25] and [28]. According to [6] and [29], the conditions of use, structures, maintenance of the wells and the discharge of liquid effluents directly compromise their use.

According to [30], proper maintenance and construction of supply wells has an impact on quality of life and public health, and it is also necessary to monitor physical, chemical and microbiological characteristics.

In order to better extract information from the samples, variables and a more detailed evaluation of the data, principal component analysis (PCA) was applied, in order to lead to a better interpretation of the data and observe similarities or differences between the groundwater samples, based on their physical-chemical characteristics shown in Table 2. In this way, the PCA projected the data into a space with 8 dimensions in the PC1, PC2, PC3, PC4, PC5, PC6, PC7 and PC8 planes (table 4).

Table 4. PCA analysis

PC	Eigenvalue	% variance
1	206.098	25,762
2	192.627	24,078
3	146.243	18,280
4	0.975321	12,192
5	0.610511	7,631
6	0.569449	7,118
7	0.28713	3,589
8	0.107914	1,349

Source: Authors, (2024).

According to the Kaiser criterion, only the two initial principal components (PC1: 25.762% and PC2: 24.078%) were considered the most significant for the explained variance of the data, as each component had an eigenvalue >1 [31]. The two most significant principal components with their respective eigenvalues, explained variance and accumulated variance are shown in Table 4. Using principal component analysis, it was identified that the best behavior of the related variables was that composed of two initial components, explaining 49.84% of the total variance of the data (Table 4).

Table 05. Principal components (PC), eigenvalues and percentage of variance explained

PC	Eigenvalue	% variance explained	% accumulated variance
1	206.098	25,762	25,762%
2	192.627	24,078	49,840%

Source: Authors, (2024).

Based on the results obtained by principal component analysis, the respective eigenvalues and percentages of variance, shown in Table 5, indicate that the first two PCs (PC1 and PC2) were responsible for 49.84% of the total variation, with PC1 being responsible for 25.76% and PC2 for 24.08% of the variations in the data. The sum of principal components I and II adequately presented the variability between the samples [32].

Table 6 shows the correlation matrix between the physical and chemical variables considered for the principal component analysis model. Using the correlation matrix, it was possible to identify the relationship between the variables.

Table 6 Correlation matrix between the physico-chemical water variables

	Ammonia (mg. L^{-1})	Chloride (mg. L^{-1})	Color (uH)	Hardness (mg. L^{-1})	Nitrate ((mg. L^{-1})	Nitrite (mg. L^{-1})	pH	Turbidity (uT)
Ammonia (mg. L^{-1})	**1,00**							
Chloride (mg. L^{-1})	0,015539	**1,00**						
Color (uH)	0,11461	0,42137	**1,00**					
Hardness (mg. L^{-1})	0,23573	-0,13428	0,097795	**1,00**				
Nitrate ((mg. L^{-1})	0,23396	-0,24336	0,30354	0,002426	**1,00**			
Nitrite (mg. L^{-1})	-0,1274	-0,25181	-0,51531	-0,20048	-0,060699	**1,00**		
pH	0,52342	-0,15668	-0,03356	0,51998	0,33953	0,074037	**1,00**	
Turbidity (uT)	-0,24809	-0,21811	-0,18619	0,17207	-0,35202	-0,16889	0,18362	**1,00**

Source: Authors, (2024).

According to [33], correlations are classified as: very low ($0.0 < r \leq 0.1$), low ($0.1 < r \leq 0.3$), Moderate ($0.3 < r \leq 0.5$), High ($0.5 < r \leq 0.7$), very high ($0.7 < r \leq 0.9$) and extremely high ($0.9 < r \leq 1.0$). According to [34], correlation coefficient values greater than 0.5 express a strong correlation between the variables. In this work, a strong correlation was observed between the variables ammonia and pH r = 0.52342 and hardness and pH r = 0.51998, a predictable result as these variables are closely related to geo-environmental conditions.

Table 07 shows the weights of the main components CP1 and CP2 for the physical-chemical variables studied.

Table 07. most significant values in bold of the principal components for the variables analyzed.

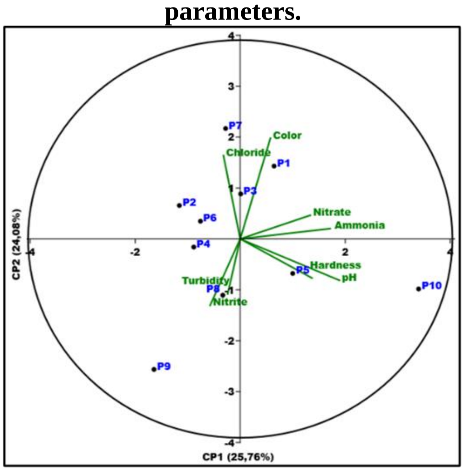
Parameters	PC 1	PC 2
Ammonia (mg. L^{-1})	**0,51695**	0,06138
Chloride (mg. L^{-1})	-0,096565	**0,49472**
Color (uH)	0,17345	**0,59678**
Hardness (mg. L^{-1})	**0,41265**	-0,23182
Nitrate ((mg. L^{-1})	**0,40306**	0,14024
Nitrite (mg. L^{-1})	**-0,17316**	-0,39413
pH	**0,57049**	-0,24549
Turbidity (uT)	**-0,071972**	-0,32606

Source: Authors, (2024).

According to the data presented in Table 7, it can be seen that the first principal component (CP1) has greater weight for the variables ammonia (mg.L^{-1}), hardness (mg.L^{-1}), nitrate (mg.L^{-1}), nitrite (mg.L^{-1}), pH and turbidity (uT) and the principal component (CP2) has greater weights for the variables chloride (mg.L^{-1}) and color (uH).

Graph 01 shows the principal components (CP1) and (CP2), displaying their respective weights, making it possible to visualize the main groupings in the set of variables.

Figure 01. Graph of the principal component analysis for the collection points and physical-chemical parameters.



Source: Authors, (2024).

Graph 1 shows that P1 and P10 had the highest ammonia levels; P2, P4 and P6 did not have high values for the physicochemical parameters analyzed; P5 had the highest hardness levels; P7 had the highest color and chloride levels; P8 had the highest nitrite levels; P9 and P10 had the highest turbidity levels; and P10 had the highest pH value.

IV. Conclusion

The water samples analyzed at collection points P1, P2, P3, P4, P5, P6, P7, P8, P9 and P10, in the surroundings of the Bom Jesus cemetery, located in the West Sector, in the city of Paraíso do Tocantins, showed pH values below and the presence of microorganisms (total and thermotolerant coliforms) above what is recommended in the legislation (Ordinance GM/MS No. 888/2021). It is important to monitor and evaluate groundwater in cemetery areas more reliably and to have prior knowledge of the chemical composition of this water, because only then will it be possible to assess whether any parameter is altered, even if its concentration is equal to or lower than that considered to be naturally occurring, as established by current legislation.

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