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Research Article

Physico-chemical and Bacteriological Characterization of Well Water Consumed in the Neighbourhoods of N'Zerekore, Guinea

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Abstract

The unsatisfactory distribution of water by the Guinea Water Company (SEG) has favoured the presence of boreholes and private wells in the urban commune of N'Zérékoré. The aim of this research is to examine the physico-chemical and bacteriological quality of water from wells in two of the town's neighbourhoods, Belle-vue and Mohomou. Nine wells in these neighbourhoods were sampled for the study. Analyses focused on 07 physical descriptors measured *in situ*; 04 chemical descriptors and 02 bacteriological descriptors, namely total coliforms and fecal coliforms determined in the laboratory. Two multivariate analyses were used to characterise the well water, including Principal Component Analysis and Hierarchical Ascending Classification. The data show a pronounced acidity in all the wells, with mean values ranging from 4.32±0.22 to 5.45±0.00. The water was poorly mineralised, but high levels of turbidity exceeding World Health Organization thresholds were recorded. All three well water points studied were contaminated with total coliform bacteria and faecal streptococci, which are good indicators of faecal contamination leading to bacteriological contamination making the water unsuitable for consumption. Principal Component Analysis (PCA) and Hierarchical Ascending Classification (HAC) were used to discriminate between the nine wells. According to the trends observed, the quality of the wells in the water analysed has deteriorated as a result of multiple factors associated with poor maintenance of the wells. These results call for action to be taken to disinfect wells, in order to guarantee a safe drinking water supply that poses no major health risk to the population.

Keywords

Bacteriological, Physico-chemical, Well Water, Diseases, N'Zérékoré, Guinea

1. Introduction

Since antiquity, water has been regarded as the "lifeblood of the Earth," essential to life on our planet and considered one of the most vulnerable and scarce natural resources. Increasing pressure is being placed on this resource particu-

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larly groundwater due to rapid population growth and rural exodus. In 2022, at least 1.7 billion people worldwide relied on a drinking water source contaminated with fecal matter. Microbial contamination resulting from fecal pollution represents the greatest risk to drinking water safety [1]. Poor water quality can result from various anthropogenic activities, including environmental pollution, improper waste disposal, and agricultural runoff. It is also often exacerbated by inadequate sanitation infrastructure and poor hygiene practices surrounding water collection and storage at the source [2]. In sub-Saharan Africa, waterborne diseases such as cholera, dysentery, typhoid fever, and viral hepatitis A and E have become prevalent, as reported by [3]. Thus, access to drinking water in both sufficient quantity and adequate quality has become a key criterion in evaluating human well being and satisfaction [4]. In both rural and urban areas, communities use groundwater via boreholes and springs, as access to sanitation infrastructure is often lacking. Research carried out in urban areas of Republic of Côte d'Ivoire by [5] described the borehole water used for domestic purposes in Abidjan's slums, and revealed the pollution factors affecting these boreholes. Water quality refers to the suitability of water for various uses. Consequently, any specific use of water must be measured in terms of acceptable levels of its physical, chemical and biological properties [6]. In particular, drinking water must meet global standards for concentrations of several elements [7]. To achieve the objective of monitoring and assessing groundwater and surface water quality, various physical, chemical and biological parameters are used for indexing. Consequently, regular water quality assessments are essential to identify these specific problems [8]. The Republic of Guinea benefits from a dense hydrographic network composed of both surface and groundwater resources, the full inventory of which remains incomplete. Thanks to this substantial water potential, populations both in urban and rural areas have found alternative means to access water, compensating for the shortcomings of supply from the Guinea Water Company (SEG).

Faced with a steadily increasing demand due to population growth and the limited capacity of the supply infrastructure, the majority of the population turns to various alternative water sources, including public standpipes, traditional wells, and other local water resources. Consequently, the region experiences a resurgence of waterborne diseases, which contribute significantly to mortality rates particularly among children.

Hence the need to carry out various physico-chemical analyses to determine the quality of water for human consumption, in order to sound the alarm about the dangers facing consumers. It is against this backdrop that this study, which looks at the pollution of water from traditional wells, has been undertaken to assess the physico-chemical and bacteriological quality of well water in the Belle-vue and Mohomou neighbourhoods of the urban district of N'Zérékoré, with the aim of identifying health risks.

2. Materials and Methods

2.1. Study Area

Guinea, a West African country, has an estimated population of nearly 14 million according to the most recent census conducted in 2021. Its capital city is Conakry. From a geo-ecological perspective, the country is divided into four major regions: Forested Guinea, Upper Guinea, Maritime Guinea, and Middle Guinea. Forested Guinea, the region in which this study was conducted, is located in the southeastern part of the country, with N'Zérékoré as its administrative center.

The topography of the Forested Region is notably rugged, characterized by hills with altitudes ranging from 400 to 800 meters, as well as significant mountain ranges such as Nimba, Ziama, and Simandou, the highest peak reaching 1752 meters above sea level. The average annual rainfall ranges between 1800 and 2300 mm. The climate is mild throughout the year, with minimal temperature variation, generally fluctuating around 25 °C [9].

This study was carried out primarily in the urban commune of N'Zérékoré, located approximately 945 km from the capital, Conakry. The city lies between 7°32' and 8°22' North latitude and 9°04' West longitude. It is the capital of the administrative region of N'Zérékoré and covers an area of 47.4 km² with a population of 196 823 (RGPH, 2014) resulting in a population density of approximately 1744 inhabitants per km². The population is distributed across 96 sectors forming 22 neighborhoods, including Belle-vue and Mohomou.

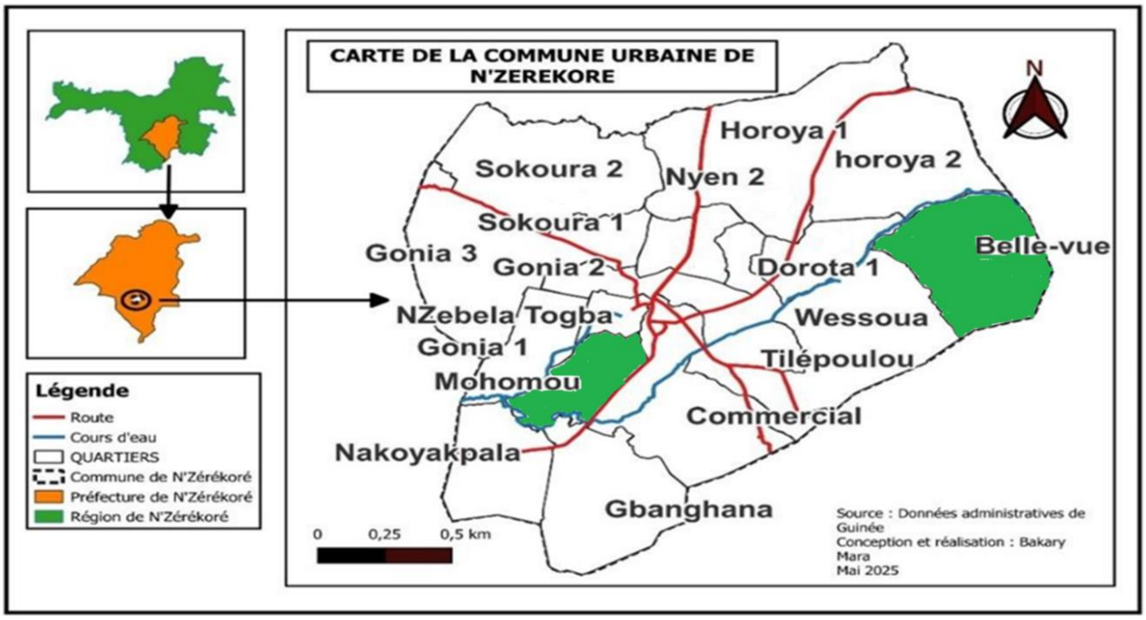

Figure 1. *Geographic plan of the sampling neighbourhoods.*

2.2. Sampling and Analysis Method

The sampling campaign was conducted between March and May 2024 (March 12-15; April 26-29 and May 20-22) on nine wells located in two different neighborhoods of the commune. Samples were taken at each well each well using a small, weighted bucket. Water samples were collected in 1500mL polyethylene bottles and analyzed immediately after collection. Before filling, the bottles were washed three times with the water to be analyzed. The bottles were filled to the brim, then the cap was sealed to prevent any gaseous interaction with the atmosphere. A total of thirteen parameters eleven physicochemical and two bacteriological were assessed both *in situ* and in the laboratory, following the techniques described by [10].

The physical descriptors, namely Temperature, pH, Electrical Conductivity, Total Dissolved Solids (TDS), and Dissolved Oxygen, were measured *in situ* by electrometric methods using a waterproof HANNA 98194 multiparameter device, 2015 version. Color was determined by photometric analysis using the 7500 photometers, based on the Beer-Lambert law. Turbidity values were obtained using a compact turbidimeter operating by nephelometry, also based on the Beer-Lambert principle.

In the laboratory, chemical parameters such as Suspended Solids, Nitrites, Nitrates, and free Chlorine were analyzed. All samples were examined within two hours of collection. Suspended Solids were measured using the gravimetric method with an analytical balance and a drying oven. Nitrites, Nitrates, and Active Chloride were quantified by photometric analysis using the 7500 photometers.

Regarding bacteriological analyses, the main parameters assessed were fecal coliforms and total coliforms, as they are sufficient to characterize the bacteriological quality of water. These microorganisms were enumerated using the membrane filtration technique as described by [10]. This method is widely used for the quantification of microbial organisms in water intended for human consumption.

2.3. Data Processing Method for the Charactezisation of the Chemical Composition of Well Water

To characterize the physicochemical and bacteriological composition of well water, both univariate and multivariate statistical methods were employed. A water sample was deemed non-compliant if at least one of the physicochemical or bacteriological parameters assessed failed to meet the standard. Principal Component Analysis (PCA) was used to analyze the composition matrix of the wells and the abiotic descriptors of the water. PCA was complemented by Hierarchical Cluster Analysis (HCA) of the first four principal components. The Euclidean distance metric was used, and the Ward's method [11] was applied, The resulting dendrogram allowed for the grouping of the wells into homogeneous clusters based on the studied variables. The mean and standard deviation of these variables were calculated. All variables were standardized prior to the analyses. The R4.4.1 software [12] was used for the statistical analyses. These methods were employed to identify and highlight the major sources of anthropogenic effects on the groundwater quality, specifically the wells under study [13]. The suitability of physicochemical and bacteriological characteristics was examined according to the water potability standards suggested by the WHO [14].

3. Results

3.1. Physico-chemical Characteristics of Water Samples

The results of the chemical analyses of well water from the Mohomou and Belle Vue districts in the urban commune of N'Zérékoré are presented in Table 1. Analysis of these results reveals a marked acidity of the water from the various wells (average pH = 4.87), as well as low mineralization, as indicated by the electrical conductivity (EC), which ranges from 66 µS/cm to 476 µS/cm with an average of 186.89 µS/cm. This trend is consistent with the Total Dissolved Solids values (average TDS = 93.33mg/L).

Regarding color, the average value indicates that the water is highly colored (51.67 TCU). Turbidity was found to be excessive in several well water samples, with values ranging from 1.65 NTU to 84.4 NTU, and an average of 17.83 NTU. Suspended Solids content ranged from 0mg/L to 55mg/L, with a mean of 12.18mg/L.

Chlorine (Cl_2) concentrations in the well water varied between 0mg/L and 0.08mg/L, with an average of 0.02mg/L. As for the concentrations of major ions, nitrates had a mean value of 12.52mg/L, while nitrites averaged 0.2mg/L. The dissolved iron content showed a mean value of 0.41mg/L, with a maximum of 1.43mg/L and a minimum of 0.16mg/L.

Furthermore, in terms of compliance with WHO standards [10], the analysis of the results generally indicates that parameters such as pH, water color, turbidity, temperature, and iron exceeded the thresholds recommended by the World Health Organization (WHO). Other indicators, notably Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chlorine, and Nitrates, showed values below the recommended limits. Finally, Suspended Solids (SS) and nitrites, highlighted in yellow, reached the threshold limits set by WHO guidelines.

Table 1. Results of physico-chemical analyses of well water in the study area.

Paramètres	Max	Min	Mean	E-T	Var	Normes OMS	Conformity
pH	5.3	4.16	4.87	0.43	0.18	6.5-8.5	
CE (µS/cm)	476	66	186.89	135.56	18 377.86	≤ 1 500	
TDS (mg/L)	238	33	93.33	67.89	4 608.75	≤ 1 000	
Coul (UCV)	210	5	51.67	72.54	5 262.50	≤ 15	
Turb (UTN)	84.4	1.65	17.83	28.97	839.15	≤ 5	
Temp (°C)	27.76	26	26.5	0.56	0.32	< 25	
SS (mg/L)	55	0	12.18	18.52	343.06	-	
NO_3^- (mg/L)	29	1.34	12.52	11.87	140.99	≤ 50	
NO_2^- (mg/L)	0.6	0.01	0.2	0.17	0.03	≤ 0.2	
Cl_2 (mg/L)	0,08	0	0.02	0.03	0.0006	0.2-0.5	
Fe (mg/L)	1.43	0.16	0.41	0.39	0.16	≤ 0.3	

3.2. Bacteriological Characteristics of Water Points

Bacteriological analysis of the water samples focused on the quantification of two indicator organisms: total coliforms and fecal coliforms present in 100mL of water. To classify water samples from the various wells, the WHO guidelines (2004) primarily rely on fecal coliforms (FC), which are considered the most reliable indicators of fecal contamination. Total coliforms (TC), which may include species of non-fecal origin, are therefore not prioritized under this rigorous WHO classification. Accordingly, Table 2 categorizes the water sources as excellent (A), acceptable (B), unfit for consumption (C), or heavily polluted (D), as defined by WHO [15].

The fecal coliform counts in wells P1, P2, P3, P4, P5, and P7 ranged from 11 to 66 CFU/100mL, placing them in category C, i.e., unfit for consumption. In contrast, water from wells P6, P8, and P9 was deemed acceptable for consumption (category B), with fecal coliform counts ranging from 3 to 6 CFU/100mL. From a bacteriological perspective, the majority of wells were therefore unsuitable for human consumption (Table 2).

Table 2. *Number of faecal coliforms in 100ml of water sampled.*

Sample	CF (UFC/100mL)	WHO category	Classification
P1	45	C	Unfit
P2	38	C	Unfit
P3	11	C	Unfit
P4	62	C	Unfit
P5	66	C	Unfit
P6	4	B	Acceptable
P7	19	C	Unfit
P8	6	B	Acceptable
P9	3	B	Acceptable

3.3. Correlations Between Different Physico-chemical and Bacteriological Water Parameters

Principal Component Analysis (PCA) performed on the 13 measured physico-chemical and bacteriological descriptors revealed that the first two principal components explain 65.85% of the total variance (Figure 2), which is sufficient for a comprehensive characterization of the sampled wells. The first principal component accounts for 41.88%, while the second explains 23.97% of the variance. Overall, the variables that exhibit strong correlations with these principal components are those that contribute most significantly to their formation.

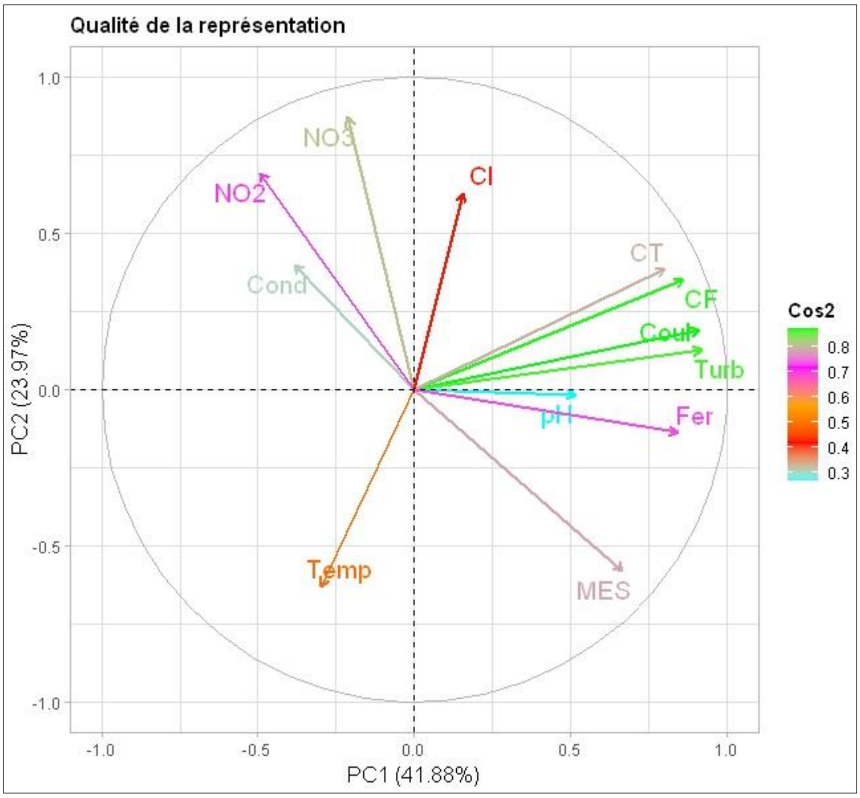

Figure 2. *Correlation of well water chemical parameters in the plane formed by the PC1 and PC2 components.*

Coul: Couleur (UCV), Temp: Température (°C), Cond: Conductivité (µS/cm), TDS (mg/l), Turb: Turbidité (UTN), CF (UFC/100ml), CT (UFC/100ml), MES (mg/l), NO2: Nitrites (mg/l), NO3: Nitrates (mg/l), Cl: Chlore (mg/L), Fer (mg/L)

Variables that exhibit a strong, positive, and statistically significant correlation with PC1 include turbidity (r = 0.919; p = 0.000), color (r = 0.912; p = 0.000), fecal coliforms (FC) (r = 0.860; p = 0.003), iron (r = 0.842; p = 0.004), and total coliforms (TC) (r = 0.802; p = 0.009). A strong and significant positive correlation was also observed between PC2 and nitrate ions (r = 0.872; p = 0.002), as well as nitrite ions (r = 0.693; p = 0.039).

On the third axis (PC3), conductivity showed a strong, positive, and significant correlation (r = 0.780; p = 0.013), while pH exhibited a strong, negative and significant correlation, indicating an inverse relationship on this axis. Finally, only chlorine concentration was strongly, positively, and significantly correlated with the fourth principal component (PC4).

3.4. Typology of Wells Sampled

The dendrogram resulting from Hierarchical Cluster Analysis (HCA) performed on the principal component scores from the PCA identified five homogeneous well groups (QP1 to QP5) (Figure 3). These groups show strong and statistically significant associations with the first two principal components (PC1: $\eta^2 = 0.992$; $p = 0.000$ and PC2: $\eta^2 = 0.891$; $p = 0.033$) (η^2: correlation ratio; v. test: variable comparison statistic across axes or groups).

1. Group 1 (QP4) includes wells P3 and P8, whose chemical composition is significantly different from that of the other wells. Water from these wells shows higher electrical conductivity (401 ± 106.07 µS/cm; p = 0.011), is more acidic (pH 4.32 ± 0.22; p = 0.039), and has a higher nitrite ion concentration (0.46 ± 0.21mg/L; p = 0.021) (Table 3).
2. Group 2 (QP5) comprises wells P6, P7, and P9, whose water contains the lowest concentrations of nitrate ions (2.18 ± 0.83mg/L), total coliforms (TC: 20.67 ± 13.32 CFU/100mL), and fecal coliforms (FC: 8.67 ± 8.96 CFU/100mL). However, these wells exhibit the highest temperatures (26.96 ± 0.70 ℃), indicating relatively warmer water.
3. Group 3 (QP3) includes wells P1 and P2, whose chemical composition is relatively close to that of group QP2. The water from these wells is relatively cooler (26.12 ± 0.09 ℃) and exhibits a lower total dissolved solids (TDS) concentration (36.00 ± 1.41mg/L).
4. Group 4 (QP2) is characterized by well P4, whose water composition differs significantly from the first three groups. It is particularly and significantly richer in chlorine (0.08 ± 0.00mg/L; p = 0.014) compared to the other groups (Table 3).
5. Group 5 (QP1) consists solely of well P5. The water from this well is significantly more colored (210 ± 0.00 CU; p = 0.021), richer in iron (1.43 ± 0.00mg/L; p = 0.006), and more turbid (84.40 ± 0.00 NTU; p = 0.015), with a very high suspended solids (TSS) content (55 ± 0.00mg/L; p = 0.014) (Table 3).

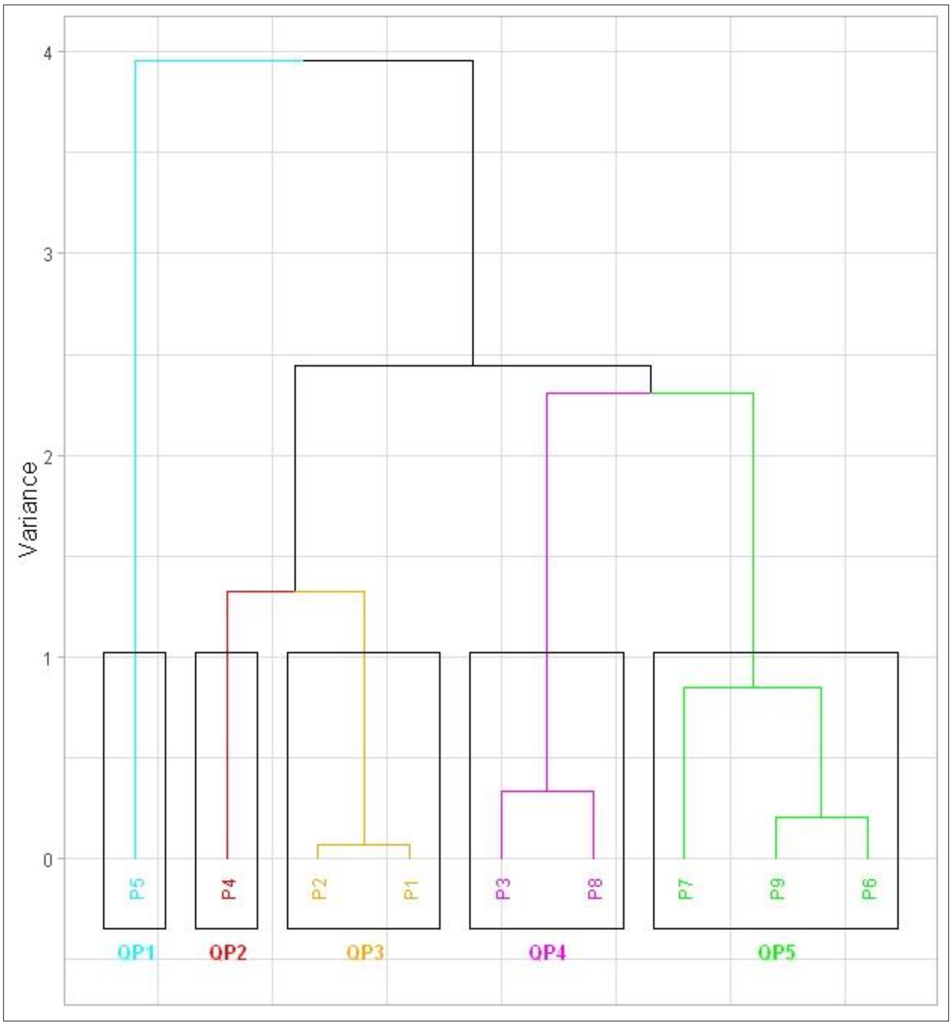

Figure 3. Dendrogram representing the Ascending Hierarchical Classification of the 09 wells.

Table 3. Descriptive characteristic (m (σ)) of the chemical composition of the water in the wells (QP1 to QP5) investigated.

Paramètre	QP1	QP2	QP3	QP4	QP5
CF	11.00 (7.07)	8.67 (8.96)	41.5 (4.95)	62.00 (0.00)	66.00 (0.00)
Chlorine	0.02 (0.00)	0.01 (0.02)	0.01 (0.01)	0.08 (0.00)	0.01 (0.00)
Conductivity	401.00 (106.07)	129.33 (61.13)	73.00 (2.83)	186.00 (0.00)	160.00 (0.00)
Colour	22.50 (17.68)	13.33 (7.64)	15.00 (0.00)	140.00 (0.00)	210.00 (0.00)
CT	29.00 (16.97)	20.67 (13.32)	68.00 (2.83)	82.00 (0.00)	92.00 (0.00)
Iron	0.28 (0.08)	0.25 (0.07)	0.32 (0.23)	0.31 (0.00)	1.43 (0.00)
Nitrate ion	19.00 (0.00)	2.18 (0.83)	11.75 (10.25)	19.00 (0.00)	2.60 (0.00)
Nitrite ion	0.46 (0.21)	0.09 (0.10)	0.20 (0.00)	0.17 (0.00)	0.07 (0.00)
TSS	1.05 (1.34)	17.33 (8.62)	0.15 (0.21)	0.20 (0.00)	55.00 (0.00)
pH	4.32 (0.22)	4.86 (0.47)	5.17 (0.18)	5.24 (0.00)	5.00 (0.00)
TDS	200.50 (53.03)	64.67 (30.57)	36.00 (1.41)	93.00 (0.00)	80.00 (0.00)
Temperature	26.47 (0.66)	26.96 (0.7)	26.12 (0.09)	26.11 (0.00)	26.33 (0.00)
Turbidity	5.53 (4.21)	4.02 (1.71)	2.48 (1.17)	48.00 (0.00)	84.40 (0.00)

4. Discussion

The physico-chemical and bacteriological analyses of well water from the Belle-Vue and Mohomou neighborhoods in the urban municipality of N'Zérékoré revealed an alarming situation. Several key water quality parameters were found to significantly exceed the World Health Organization (WHO) standards for safe drinking water. These results indicate a clear deterioration in groundwater quality, most likely linked to anthropogenic pressures such as inadequate sanitation, waste disposal practices, and unregulated urban development.

Indeed, from a physico-chemical perspective, the well water samples exhibited relatively low temperatures, ranging between 25℃ and 26℃. These values are consistent with those reported in previous studies on groundwater in the Pointe-Noire region of Cameroon, suggesting similar hydrogeological and climatic conditions [16, 17]. However, according to WHO guideline values these temperatures are not compliant with recommended standards. It is important to note that water temperatures between 25℃ and 28℃ provide favorable conditions for the proliferation of environmental microorganisms [18]. This suggests that the elevated temperatures observed in the well water could create favorable conditions for microbial proliferation, especially under tropical climatic conditions where warm environments accelerate bacterial growth and survival.

Regarding pH, the well waters in N'Zérékoré are acidic and potentially aggressive to the gastrointestinal tract. with average values ranging from 4.32 to 5.24. These observations are consistent with the findings of [19], who reported average pH values between 5.75 and 6.40, emphasizing that water with a pH below 6.5 is corrosive, while values above 8.5 may lead to scaling risks. Similarly, [20] attributed the acidity of groundwater in the Abidjan municipalities (Ivory Coast) to the decomposition of organic matter around residential areas.

In the same vein, this acidic character of well water could also be linked to runoff infiltration during the rainy season, as observed by [21]. Furthermore, [22] highlighted that water acidity may result from the acidic geochemical nature of regional soils or from anthropogenic inputs, which may in turn promote the mobilization of metals such as iron. This situation easily explains the presence of iron in our samples, with concentrations close to the WHO limit values, except for well P5 located in the Mohomou neighborhood, where the levels greatly exceed the recommended guideline values. [23] noted that, despite the toxicity of iron at low concentrations, high levels of iron can alter the taste of water and promote the formation of biofilm on the surfaces of well slabs and boreholes.

The average values for TDS (93.33mg/L) and electrical conductivity (186.89 µS/cm) obtained for all the water points indicate low mineralization of the water. These conductivity values are similar to those reported by [24, 19]. However, the high turbidity observed in some of our samples (84.4 NTU), significantly above the 5 NTU threshold set by the WHO [14], clearly indicates the presence of suspended particles, as well as microorganisms and organic debris in the water. In Burkina Faso, [25] highlighted high turbidity levels in well water, which were associated with the absence of well covers, direct runoff into the wells, and the use of contaminated ropes and buckets.

The average color value was 51.67 UCV, significantly higher than the 15 UCV threshold accepted by the WHO. This coloration is likely due to the oxidation of iron [26]. These values are higher than those reported by [27], whose study on well water in Congo-Brazzaville found color values ranging from 7 to 10 UCV. Furthermore, the nearly zero levels of active chlorine in our water samples suggest an absence of treatment, which could potentially exacerbate microbiological risks.

The presence of chemical elements, particularly nitrate ions, generally showed values below the WHO threshold. However, values significantly exceeding 20mg/L were recorded in wells P1, P3, P4, and P8, which may indicate moderate nitrogen pollution. This is likely linked to the proximity of latrines near household compounds and water sources, or could be a result of agricultural and domestic effluents. These findings align with the work of [28]. As for nitrites, certain threshold values were reached in a few wells, indicating a concerning situation that could be the result of recent contamination by fecal pollution.

From a bacteriological perspective, indicator organisms, namely total coliforms and fecal coliforms, were found in almost all the water samples, indicating widespread contamination, as none of the samples met the WHO standards for potable water (0 CF/100mL). Among the nine wells studied, 33.3% had an acceptable level, while 66.7% were deemed unsuitable for drinking, highlighting a public health risk that could be exacerbated. A study conducted by [29] revealed that 70% of well water samples they analyzed were unfit for consumption due to fecal contamination. According to [30], the concentration of indicator organisms of bacterial pollution is higher in well water compared to source water and boreholes. This is likely because well water is stagnant, promoting the deposition of suspended particles.

Multivariate analyses, specifically Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA), were used to spatially structure the pollution through the grouping of variables, highlighting anthropogenic activities, particularly the presence of nitrates, fecal coliforms, and high turbidity, confirming that anthropogenic factors play a decisive role in the deterioration of water quality. The study of spatial variability was demonstrated by [31] in Bamako, Mali, where significant disparities were observed between neighborhoods in terms of water quality, which were related to socio-environmental conditions.

5. Conclusions

The physico-chemical and bacteriological quality of well water in the Mohomou and Belle-vue neighborhoods of the urban municipality of N'Zérékoré was evaluated, revealing that the water does not meet the WHO guidelines and recommendations regarding drinking water standards. The high levels of certain parameters (Iron, pH, Turbidity, Conductivity), along with their non-compliance with the WHO thresholds, indicate pollution of both natural origin, related to the geological nature of the aquifers, and anthropogenic sources, such as domestic wastewater infiltration, the use of animal manure fertilizers, and the proximity of deep latrines. Bacteriologically, 70% of the well water analyzed was contaminated with fecal contamination germs and should not be consumed without prior treatment. Furthermore, the wells were classified based on their pollution levels using Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA), highlighting the need for targeted public health interventions. Preventive measures, such as chlorination, as well as the use of coagulants like quicklime and aluminum sulfate, should be implemented to mitigate the pollution of these well waters.

Abbreviations

WHO	World Health Organization

Conflicts of Interest

The authors declare no conflicts of interest.

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