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ASSESSMENT OF THE PHYSICOCHEMICAL AND BACTERIOLOGICAL QUALITY OF BOREHOLE WATER USED IN THE URBAN COMMUNE OF BOKÉ, REPUBLIC OF GUINEA

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ABSTRACT

Borehole water represents a critical source of drinking water in many rural regions, particularly in Guinea, where it often serves as the primary supply. However, such water sources are susceptible to contamination from both environmental and anthropogenic activities, potentially posing significant public health risks. This study aimed to evaluate the physicochemical and bacteriological quality of borehole water consumed in the urban municipality of Boké, with the objective of determining its potability and identifying possible health hazards. The physicochemical parameters assessed included pH, turbidity, electrical conductivity, total dissolved solids (TDS), and the concentrations of iron, nitrites, and nitrates. Ten (10) borehole water samples were collected from the neighborhoods of Yomboya, Lambagni, Dantaré, Kofiya, and 400 Buildings, areas not supplied by the Guinean Water Utility (SEG). The physicochemical analysis revealed pH values ranging from 4.6 to 7.45, turbidity levels between 0.17 and 4.03 NTU, electrical conductivity from 38 to 255 µS/cm, and total dissolved solids (TDS) ranging from 51.82 to 196.24 mg/L. Nitrate concentrations varied between 5.75 and 23.17 mg/L, nitrite levels ranged from 0.03 to 0.14 mg/L, and iron concentrations were between 0.001 and 0.23 mg/L. Among the ten samples analyzed, 60% demonstrated acceptable microbiological quality. However, samples 6, 9, and 10 exhibited significant fecal contamination, suggesting likely pollution from human or animal sources. Sample 10 was particularly concerning, exhibiting elevated levels of total coliforms, thermotolerant coliforms, fecal streptococci, and mesophilic aerobic flora, rendering the water unsuitable for consumption without prior treatment. Statistical analysis performed using STATA software revealed substantial variability in borehole water quality, underscoring the necessity of regular monitoring and the implementation of corrective measures to ensure consumer health safety.

Keywords: Borehole water, physico-chemical quality, bacteriological quality, potability, health risks, Boké.

1. INTRODUCTION

Access to safe drinking water remains a major public health concern, particularly in developing countries. In Africa, groundwater from wells constitutes the primary source of drinking water, and its use is steadily increasing due to growing population demands [1]. These facilities help reduce reliance on surface water, which is often vulnerable to various sources of contamination; however, the quality of groundwater is not always guaranteed [2] [3]. According to WHO and UNICEF, boreholes are considered improved water sources, with approximately 200 million people in sub-Saharan Africa depending on them for their daily water needs [4].

However, numerous studies have highlighted the vulnerability of groundwater to contamination from various sources. These pollutants may be of natural origin—such as bacteria, viruses, nitrates, heavy metals, or complex organic compounds—or result from anthropogenic activities, including industrial operations, agricultural runoff, and domestic waste. Such contamination compromises the potability of groundwater and poses significant health risks to the population [1][2].

In bauxite mining areas, aluminum and iron are the primary contributors to water pollution. Furthermore, the disruption and excavation of natural ecosystems can mobilize additional contaminants, including arsenic (As), nickel (Ni), mercury (Hg), cadmium (Cd), lead (Pb), and other heavy metals, which may further degrade the quality of drinking water [5]. Thus, regular monitoring of water quality is essential to protect public health and to ensure the sustainable management of water resources [6].

The Boké prefecture in Guinea is currently an important mining area where several companies compete in bauxite extraction [5]. The urban municipality of Boké, in particular, is experiencing rapid demographic growth, accompanied by intensive development of mining and agricultural activities, which could potentially compromise groundwater quality. Despite these environmental and health concerns, few studies have been conducted to assess the quality of well water in this area.

In this context of increased vulnerability, it is essential to conduct an assessment of the physico-chemical and bacteriological quality of these waters in accordance with current international standards.

The objective of this study was to evaluate the quality of groundwater used in the urban municipality of Boké by analyzing various physico-chemical and microbiological parameters, in order to determine compliance with drinking water standards and identify potential associated health risks.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in the urban commune of Boké, located in the northwest of the Republic of Guinea. This region is characterized by a humid tropical climate with an extended rainy season. It is undergoing rapid urbanization, marked by significant industrial and mining development, as well as a strong reliance on borehole water for domestic needs. The study area lies between longitudes 14°00’ and 15°00’ West, and latitudes 10°00’ and 11°00’ North. Physically, it features diverse landforms, including plains, plateaus, hills, and depressions, with elevations ranging from 5 to 217 meters. The soils are primarily lateritic, hydromorphic, alluvial, and occasionally skeletal in nature. Their texture consists of approximately 0 to 45% clay, 20% sand, and 30% silt. Additionally, these soils exhibit variable permeability and porosity depending on the location, which facilitates water infiltration [7].

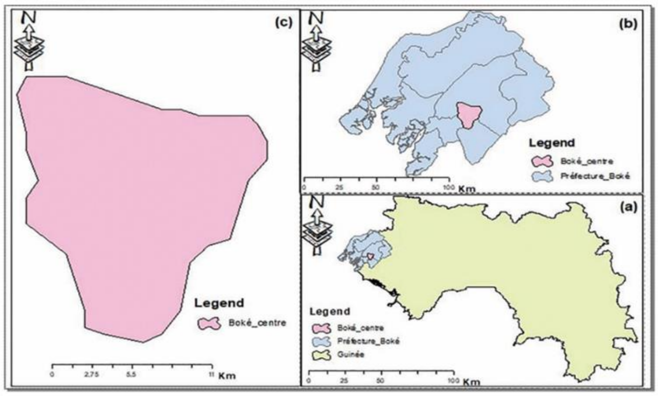

Figure : Carte de location de la commune urbaine de Boké (Boké centre)

2.2. Sampling

Ten (10) water samples were collected in August 2025 from ten (10) wells located in the urban commune of Boké, comprising four (4) community wells (see image a) and six (6) private wells (see image b). At each site, sampling was performed using sterile 1-liter plastic bottles. Prior to sampling, water was allowed to flow for two minutes to flush the pipes and eliminate stagnant water that could affect the results. The bottles were then rinsed three times with water from the respective well (see image c) before being completely filled [7]. All samples were properly labeled, stored in a cooler, and promptly transported to the National Quality Control Office (ONCQ) laboratory in Matoto-Conakry (see image d), following the protocols recommended by the American Public Health Association (APHA) [8].

2.3. Physico-chemical analysis

The physicochemical analysis focused on pH, turbidity, electrical conductivity, total dissolved solids, as well as concentrations of iron, nitrites, and nitrates.

pH Measurement

The pH of the water samples was measured using an electrometric method with a pH meter calibrated beforehand with standard buffer solutions at pH 4, 7, and 10. For each sample, a combined glass electrode was immersed, and the reading was recorded once the signal stabilized [8].

Turbidity Measurement

The turbidity of the water samples was measured using a nephelometric turbidimeter (see image e). This method is based on the detection of light scattered at a 90° angle. The results are expressed in nephelometric turbidity units (NTU) [9] [10].

Measurement of Electrical Conductivity

The electrical conductivity of the water samples was measured using a conductivity meter (see image f). The measuring probe was immersed in each sample, and conductivity values were expressed in microsiemens per centimeter (µS/cm), with temperature compensation to 25 °C to ensure reliable comparisons between sampling sites [11] [12].

Determination of Total Dissolved Solids (TDS)

The total dissolved solids (TDS) concentration was estimated based on the electrical conductivity (EC) measured using a conductivity meter (see image f) calibrated at 25 °C. The EC values were then converted to TDS (mg/L) using an appropriate conversion factor, depending on the water's ionic composition [13].

Determination of Nitrate concentration

The concentration of nitrates (NO_3^-) in the groundwater samples was determined using UV spectrophotometry (see image f), by measuring absorbance at 220 nm with a correction at 275 nm to minimize interference from organic matter. The results are expressed in milligrams per liter (mg/L) of NO_3^- [14] [15].

Determination of Nitrite Concentration

The concentration of nitrites (NO_2^-) in the borehole water samples was determined by spectrophotometry (see image f), using the Griess reaction. In this method, nitrites react in an acidic medium with diazotizing reagents to form a colored azo compound, the intensity of which is measured spectrophotometrically [16].

Determination of Iron Concentration

The concentration of iron (Fe) in the borehole water samples was determined by spectrophotometry (see image f), following the reduction of total iron to ferrous iron (Fe^{2+}) and its complexation with 1,10 phenanthroline to form an orange-red colored complex. Quantification was carried out by measuring the absorbance of the complex at approximately 508 nm, using a calibration curve established with iron standard solutions [17].

2.4. Bacteriological Analysis

The bacteriological analysis focused on the detection and enumeration of fecal contamination indicators. The microbiological parameters assessed included aerobic mesophilic flora, total coliforms, fecal (thermotolerant) coliforms, and fecal streptococci. Results were expressed in CFU/mL (colony-forming units per milliliter) and compared with WHO standards, which recommend the total absence of these microorganisms in 100 mL of drinking water.

Enumeration of Total Aerobic Mesophilic Flora

The enumeration of total aerobic mesophilic flora (TAMF) was performed by surface plating on nutrient agar (see image g) using successive decimal dilutions of the samples. The plates were incubated at 30 °C for 48 to 72 hours (see image h), following the standard aerobic plate count method (see image i) [18].

Enumeration of Total Coliforms

The enumeration of total coliforms was performed using the membrane filtration method. A volume of 100 mL of water was filtered through a sterile 0.45 µm membrane filter, which was then placed on a selective medium (Lactose Desoxycholate Agar) (see image g). Incubation was carried out at 35 ± 0.5 °C for 20 to 24 hours (see image h). After incubation, characteristic colonies were counted (see image i), and the results expressed as colony-forming units per 100 mL (CFU/100 mL) [19].

Enumeration of Thermotolerant Coliforms

The enumeration of thermotolerant coliforms (indicators of fecal contamination) was performed using the membrane filtration method, followed by incubation on a selective medium (Lactose Deoxycholate Agar) (see image g). A volume of 100 mL of water was filtered through a sterile 0.45 µm membrane; after incubation at 44.5 ± 0.5 °C (see image h), characteristic colonies were counted (see image i) and results expressed as CFU per 100 mL (CFU/100 mL) [19].

Enumeration of Fecal Streptococci

The enumeration of fecal streptococci was performed by membrane filtration. A volume of

100 mL of water was filtered through a sterile 0.45 µm membrane, which was then placed on a selective medium (Streptococcus agar) (see image g) and incubated at 41 °C (see image h). After incubation, characteristic colonies were counted (see image i), and results expressed as colony-forming units per 100 mL (CFU/100 mL) [20].

2.5. Statistical Analysis

Data from physicochemical and bacteriological The data from the physicochemical and bacteriological analyses were processed using STATA version 15.1. Descriptive statistics (means, standard deviations, minima, maxima) were used to characterize the measured parameters. Comparative tests against WHO standards were performed to assess sample compliance. A significance level of $p < 0.05$ was applied to determine the statistical relevance of observed differences. This approach allowed identification of significant variations and detection of non-compliant parameters that may pose health risks.

3. RESULTS

3.1. Physicochemical Parameters

The table below presents the results of physicochemical analyses conducted on ten borehole water samples collected from the urban municipality of Boké. The parameters measured include pH, turbidity, electrical conductivity, total dissolved solids (TDS), as well as concentrations of nitrates (NO_3^-), nitrites (NO_2^-), and iron (Fe). These parameters are crucial for assessing the quality of water intended for human consumption, in accordance with World Health Organization (WHO) standards. The variations observed among the samples help identify potential pollution sources and evaluate the overall condition of the borehole water studied. The collected data will serve as a basis for comparative discussion and interpretation of associated health risks.

Table 1: Results of the physico-chemical analyses of the borehole water

Analyzed settings	pH	Turbidity (NTU)	Conductivity (µS/cm)	DSC (mg/L)	Nitrates (mg/L)	Nitrites (mg/L)	Iron (mg/L) (mg/L)
E1	7,2	2,03	87	81,01	15,3	0,06	0,121
E2	5,33	3,83	38	51,82	11,31	0,07	0,047
E3	6,56	4,03	212	163,14	17,44	0,11	0,096
E4	6,7	1,9	198	165,33	5,75	0,1	0,201
E5	4,6	0,17	89	84,34	7	0,11	0,001
E6	6,87	0,67	236	181,61	12,04	0,14	0,17
E7	7,45	0,96	255	196,24	23,17	0,1	0,23
E8	6,6	1,03	125	99,02	13,55	0,08	0,184
E9	5	0,23	59	55,91	19,33	0,13	0,19
E10	6,4	3,72	162	136,52	10,01	0,03	0,096

pH Measurement

Most samples have a pH ranging from 4.6 to 7.45, indicating neutral to slightly acidic conditions, with the acceptable range for drinking water being 6.5 to 8.5. Values at the lower end (4.6 to 5) may suggest acidity that could contribute to pipe corrosion.

Determination of Turbidity

The turbidity values obtained in this study range from 0.17 to 4.03 NTU, indicating generally low to moderate turbidity levels that comply with recommended drinking water standards. These low values reflect clear water with minimal suspended particles. According to WHO guidelines, turbidity should not exceed 5 NTU for safe drinking water.

Determination of electrical conductivity

The electrical conductivity values measured in this study, ranging from 38 to 255 µS/cm, indicate a relatively low mineralization of the groundwater, generally complying with drinking water standards.

Determination of the dissolved salt content (DSC)

The total dissolved solids (TDS) concentrations obtained range from 51.82 to 196.24 mg/L, indicating low mineralization of the groundwater. These values are well below the WHO guideline limit of 1000 mg/L for drinking water, reflecting an overall satisfactory physicochemical quality suitable for human consumption.

Determination of Nitrate Concentration

The measured nitrate concentrations, ranging from 5.75 to 23.17 mg/L, indicate moderate contamination of the groundwater but generally remain below the WHO's critical threshold of 50 mg/L for drinking water.

Determination of Nitrite Concentration

The nitrite (NO_2^-) concentrations obtained range from 0.03 to 0.14 mg/L, remaining below the WHO's maximum recommended limit of 0.2 mg/L for drinking water. These values indicate an overall acceptable quality regarding nitrite contamination; however, the presence of nitrites, even at low concentrations, warrants special attention due to their potential toxicity, especially for infants.

Determination of Iron Concentration

The iron concentrations obtained in this study range from 0.001 to 0.23 mg/L, which, although generally below the WHO guideline value of 0.3 mg/L for drinking water, indicate a notable presence of iron in some of the sources analyzed. This variability can be explained by local geological factors, borehole depth, or the corrosion status of the pumping equipment.

4. BACTERIOLOGICAL PARAMETERS

The table below presents the results of microbiological analyses conducted on ten groundwater samples, showing the counts of total aerobic mesophilic flora (MATF), total coliforms, thermotolerant coliforms, and fecal streptococci, expressed as colony-forming units (CFU) per specified volume.

Germs/100mL				
Samples	**Mesophilic Aerobic Total Flora (MATF) (UFC/mL)**	**Total Coliforms (UFC/100 mL)**	**Thermotolerant Coliforms (UFC/100 mL)**	**Fecal Streptococci (UFC/50 mL)**
E1	84	0	0	0
E2	44	0	0	0
E3	86	0	0	0
E4	90	0	0	0
E5	55	0	0	0
E6	150	70	6	2
E7	35	0	0	0
E8	5	0	0	0
E9	388	16	2	0
E10	54	213	145	0

Table 2: Results of bacteriological analysis of well water

Total Aerobic Mesophilic Flora (TAMF)

The total aerobic mesophilic flora counts range from 5 to 388 CFU/mL, with an estimated average of approximately 99 CFU/mL. According to WHO guidelines, drinking water should be free of microbial contamination or contain less than 100 CFU/mL. Most of the analyzed samples comply with this standard, indicating generally acceptable microbiological quality. However, sample 9 exhibits a notably high count of 388 CFU/mL, suggesting probable microbial contamination. This anomaly may be due to proximity to pollution sources, local degradation of water quality, or insufficient protection of the well against infiltration.

Total Coliforms

Total coliforms were detected in three out of ten samples, specifically in sample 6 (70 CFU/100 mL), sample 9 (16 CFU/100 mL), and sample 10 (213 CFU/100 mL). According to World Health Organization (WHO) guidelines, drinking water should contain no total coliforms (0 CFU/100 mL). The presence of these bacteria in these samples indicates possible fecal contamination or poor hygiene conditions around the well sites. The very high count observed in sample 10 is particularly concerning and represents a significant health risk that requires immediate corrective action.

Thermotolerant Coliforms

Thermotolerant coliforms were detected in three samples: sample 6 (6 CFU/100 mL), sample 9 (2 CFU/100 mL), and sample 10 (145 CFU/100 mL). According to WHO standards, their presence in drinking water is unacceptable (0 CFU/100 mL), as it indicates recent fecal contamination. The high count in sample 10 reflects significant direct fecal pollution, posing a serious public health risk. Sample 6 is also concerning, showing simultaneous contamination by total coliforms, thermotolerant coliforms, and fecal streptococci—suggesting a highly polluted environment or inadequate protection of the water source.

Fecal Streptococci

Fecal streptococci were detected in only one of the ten samples, specifically sample 6, with a concentration of 2 CFU/50 mL. Their presence is a reliable indicator of fecal contamination of human or animal origin and reinforces the concerning results already observed in the same sample, which also tested positive for total and thermotolerant coliforms. This combination reflects a significant level of biological pollution, severely compromising the microbiological safety of the water. These findings highlight the urgent need for corrective and preventive measures to protect public health and ensure safe drinking water.

5. DISCUSSION

5.1. Physicochemical Parameters

Measurement of pH

The results are comparable to those reported by [21] in their study on the quality of groundwater in boarding schools around the Kwame Nkrumah University of Science and Technology in Ghana, where the average pH was 5.646 ± 0.389. This level of acidity can be attributed to the decomposition of natural organic matter, but also to anthropogenic pollution, particularly from domestic wastewater or certain mining activities that disrupt the chemical equilibrium of aquifers.

The results are slightly lower than those reported by [22] in their study on the safety of borehole water as an alternative drinking water source, where pH values ranged from 4.33 to 7.03. They also fall within the range observed by [23] in the village of Nwadzekudzeku, Limpopo Province, South Africa, where groundwater pH values ranged from 6.96 to 7.76. These generally neutral to slightly alkaline waters indicate a limited influence of acidic or polluted sources. This consistency suggests that certain physicochemical characteristics of groundwater, particularly in rural or peri-urban settings, may remain relatively stable across different regions, especially in the absence of significant industrial activity.

However, the results of this study are generally lower than those reported by [24] in Axum (Ethiopia), where pH values ranged from 7.2 to 8.2 in groundwater derived from volcanic formations. This discrepancy may be attributed to local geological conditions, soil composition, borehole depth, or the limited influence of anthropogenic activities in that region. In contrast, the pH values below 6.5 observed in several of our samples are of concern, as they fall outside the WHO recommended range for drinking water (6.5 to 8.5). Such acidity may promote pipe corrosion and potentially impact human health, particularly by altering the palatability of water and facilitating the leaching of toxic metals.

Moreover, the results of this study are consistent with those reported by [25], who observed pH values ranging from 5.240 to 7.850 in their investigation of interactions between pH and other water quality parameters in groundwater and surface water systems. This concordance reinforces the notion that pH, as a fundamental indicator of water quality, is significantly influenced by a combination of environmental conditions, geological formations, and anthropogenic activities.

Determination of Turbidity

The results obtained are comparable to those reported by [22], who recorded turbidity values ranging from 0.57 to 2.31 NTU in their study on the safety of borehole water used as an alternative drinking water source. This similarity suggests comparable physicochemical characteristics. However, the slightly higher values observed in the present study may reflect a greater concentration of suspended particles, potentially due to increased anthropogenic influence or inadequate maintenance of the borehole infrastructure.

The results of this study are also generally lower than those reported by [26] in the Limpopo province of South Africa (0.17 to 3.21 NTU), although there is some overlap in the observed ranges. This difference may be attributed to variations in geological formations or groundwater abstraction practices. In contrast, the turbidity values in this study are significantly lower than those reported by [27] in N'Zérékoré (Guinea), where values ranged from 1.65 to 84.4 NTU, and by [28] in the coastal region of Lomé (Togo), with values ranging from 0.2 to 21.0 NTU. These elevated levels suggest more severe contamination, potentially resulting from diffuse pollution sources, soil erosion, or the infiltration of suspended solids into shallow aquifers.

The data from this study are closely aligned with those reported by [29] in the local government area of Ewekoro (Ogun State, Nigeria), where turbidity values ranged from 1.2 to 4.2 NTU. This similarity reinforces the relevance of the present findings within a West African context characterized by comparable hydro-environmental conditions.

Finally, the values obtained in this study are slightly higher than those reported by [30] in Ouagadougou (Burkina Faso), where the average turbidity was 1.27 ± 1.25 NTU. This difference may be attributed to local factors such as soil composition, borehole depth, the natural filtration capacity of the terrain, or the technical condition and maintenance of the water infrastructure.

Determination of Electrical Conductivity

The results of this study are lower than the average reported by [31] in their research on the physicochemical characterization of domestic borehole water in Daloa (central-west Côte d'Ivoire), where an average conductivity of 246.2 ± 162.6 µS/cm was recorded.

However, the values obtained in this study fall within the range observed by [32] in the Cascades region of Burkina Faso, where electrical conductivity varied between 22 and 514 µS/cm, reflecting significant variability linked to local geological characteristics and mineralization sources.

In contrast, the results obtained in this study are significantly lower than those reported by [33] in the Samba Dia region (central-west Senegal), where conductivity levels ranged from 107 to 25,200 µS/cm, indicating high mineralization, particularly in certain saline areas or zones influenced by the sea. Similarly, the values in this study are much lower than those observed by [34] in the semi-arid regions of central Tunisia, where groundwater conductivity ranged from 1,544 to 3,960 µS/cm, reflecting highly mineralized water often unsuitable for consumption without treatment.

Finally, the results of this study are also lower than those reported by [35] in a semi-arid river basin in Niger, where conductivity ranged from 78 to 556 µS/cm. Although the ranges partially overlap, the data from this study mostly fall within the lower part of the range, suggesting a lesser influence of dissolved salts or anthropogenic inputs.

The low conductivity observed in the borehole waters of Boké could be explained by the depth of the wells, the low natural salinity of the aquifers, or a low ionic load due to limited mineralization, which is generally favorable for drinking water quality.

Determination of dissolved salt concentration

In comparison, the results of this study are significantly lower than those reported by [36] in their study conducted in the Technopole area of Pikine (Senegal), where groundwater had an average TDS of 3200 mg/L. These high levels indicate marked salinization, probably due to seawater intrusion and anthropogenic inputs related to urbanization.

Similarly, [37] observed TDS values ranging from 149 to 623 mg/L in the Niayes region at Mboro (Senegal). Although the lower end of this range is close to the interval observed in this study (51.82 to 196.24 mg/L), the reported maximum value is significantly higher, indicating a greater level of mineralization. This difference could be attributed to local geological factors, slow aquifer recharge, or more pronounced human activities. Furthermore, the results of this study are also lower than those reported by [38] in their study on the influence of hydrology and sanitation on groundwater quality in parts of the western Bengal basin, where TDS ranged from 314 to 343 mg/L. This higher level may be linked to increased natural mineral loads or prolonged interaction between water and geological formations.

Finally, in the coastal sedimentary basin of Mauritania, [39] reported highly variable concentrations ranging from 79 to 74,019 mg/L, revealing severe salinization in some areas due to intense evaporation and seawater intrusion. Compared to these results, the data from this study suggest the absence of significant saline influence in the studied area. These comparisons indicate that the groundwater in the urban commune of Boké has low mineralization, compatible with domestic use. The low TDS content reflects good physicochemical quality, relatively preserved from major marine or anthropogenic influences, unlike other regions in West Africa where salinity limits water use.

Determination of Nitrate Concentration

The results of this study are higher than those reported by [40] in their evaluation of nitrate and nitrite levels in borehole water from the Southern and Northern regions of Côte d'Ivoire, where average values of 12.08 ± 2.11 mg/L (Lower Coast) and 11.03 ± 3.18 mg/L (Korhogo) were recorded. This difference may be explained by variability in pollution sources, notably the intensity of agricultural activities or the lack of sanitation systems.

The concentrations obtained in this study are also higher than those reported by [41] in Lagos State, Nigeria, where nitrate levels in groundwater ranged from 0.01 to 0.15 mg/L, indicating very low contamination. Similarly, [42] reported concentrations ranging from 2.4 to 6.4 mg/L in the oil-producing state of Bayelsa (Nigeria), which are lower than those observed in the present study. This difference, despite the high industrial pressure in the region, could suggest a less pronounced influence of diffuse anthropogenic sources in their study area.

In contrast, the results of this study are lower than those observed in more critical areas. For example, [43] measured nitrate concentrations ranging from 16 to 380 mg/L in shallow well waters in northeastern Saudi Arabia, where intensive agriculture and the shallow depth of aquifers exacerbate the risk of pollution. Similarly, [44] reported nitrate levels in Morocco exceeding 100 mg/L, highlighting critical pollution due to excessive use of nitrogen fertilizers and lack of control over domestic and agricultural discharges. Finally, [45], in a global analysis of groundwater nitrate pollution, identified average values above 50 mg/L in several regions of Europe and North Africa, placing the results of this study in a moderate risk zone, but not an alarming one.

These comparisons indicate that although the nitrate concentrations observed in this study remain below the critical threshold set by the WHO (50 mg/L), they nevertheless reflect a significant influence of human activities, notably agricultural, domestic, and mining activities. This situation highlights the need for continuous monitoring of groundwater quality, as well as the implementation of appropriate preventive measures to limit contamination risks and sustainably preserve groundwater resources.

Determination of Nitrite Concentration

By comparison, the results of this study are lower than those reported by [41] in their study conducted in Lagos State, Nigeria, where nitrite concentrations in various groundwater sources ranged from 0.10 to 0.23 mg/L, some exceeding the WHO standard (0.2 mg/L). This could reflect more pronounced pollution, likely of anthropogenic origin (domestic or agricultural discharges).

Moreover, the values obtained in this study are also lower than the average concentration of 0.32 mg/L reported by [40] in their assessment of nitrates and nitrites in groundwater from the southern and northern regions of Côte d'Ivoire. This concentration exceeds the WHO limit, indicating concerning nitrite contamination in certain areas.

Furthermore, the concentrations found in this study are higher than the very low levels reported by [46] in their study on groundwater quality in Ouagadougou (Burkina Faso), which recorded average values of 0.005 ± 0.006 mg/L. This difference could be explained by factors such as well depth, natural soil filtration, or the intensity of nearby human activities.

Thus, although the results of this study remain within drinking water standards, they indicate a slight presence of nitrites that may stem from local contamination by domestic or industrial waste, latrine infiltration, or the use of nitrogen fertilizers. Regular monitoring is therefore recommended to prevent any progression to critical concentrations.

Determination of Iron Concentration

The iron concentrations obtained in this study are higher than those reported by [46] in their assessment of groundwater quality in the municipality of Ouagadougou, Burkina Faso. In their study, the iron content was consistent across all samples, with a concentration of 0.02 mg/L, except for sample No. 6, which had a slightly lower value of 0.01 mg/L. This difference suggests that the untreated waters analyzed in our study naturally have higher iron levels, highlighting the need for appropriate pretreatment to prevent aesthetic issues such as metallic taste, discoloration, and deposits in distribution networks.

The results obtained in this study reveal iron concentrations lower than those reported by [47] in their research on the removal of iron and manganese through aeration and coagulation-flocculation processes in borehole water in the city of Rumonge (Burundi), where a concentration of 16.5 mg/L was recorded.

The results of this study are close to those found by [48] in their investigation of the microbiological and physicochemical quality of groundwater and associated pollution risk factors in Ouagadougou, Burkina Faso, where concentrations ranged from 0 to 0.39 mg/L.

Furthermore, the concentrations observed in this study are higher than those reported by [49] in Akure (Nigeria), where iron levels in borehole water ranged from 0.023 to 0.030 mg/L. This suggests possible regional variability influenced by soil composition and underlying geology.

Finally, the iron concentrations obtained in this study remain lower than those reported by [50] in Yenagoa (Bayelsa State, Nigeria), where levels ranged from 0.1 to 0.8 mg/L, with some values significantly exceeding WHO standards. This difference could be explained by increased anthropogenic contamination, particularly related to local industrial or oil-related activities.

The results of this study reveal moderate levels of iron, which comply with WHO standards but still require careful attention. The presence of iron, even at low concentrations, can affect the aesthetic quality of the water and underscores the need for continuous monitoring or simple treatment methods in certain areas.

6. BACTERIOLOGICAL PARAMETERS

Total Aerobic Mesophilic Flora (TAMF)

The concentrations of total aerobic mesophilic flora (TAMF) obtained in this study are generally lower than those reported by [51], who, in their assessment of the bacteriological quality of well and borehole water in Lomé (Togo), recorded values ranging from 0 to 308,427 CFU/mL. In contrast, the results of this study are higher than those reported by [52] in their study on borehole water within the campus of Polytechnique Mai Idris Alooma and its surroundings, where concentrations of up to 85 CFU/100 mL were observed. These discrepancies could be explained by differences in environmental conditions, hygiene practices, or the vulnerability of the sampled structures.

Total Coliforms

The total coliform concentrations obtained in this study are generally comparable to those reported by [53] in their assessment of the bacteriological quality of borehole water used at Shalom University of Bunia, where values ranged from 5 to 2,424 CFU/100 mL depending on the sample. In contrast, they are higher than the results reported by [54] in their study conducted in the Gulf prefecture (Togo), which recorded a maximum concentration of 11 CFU/100 mL. However, the data from this study remain lower than those reported by [51], who observed levels of up to 1,720 CFU/mL in well and borehole waters in Lomé. These differences could be explained by the variety of contamination sources, borehole depths, hygiene practices, or the protection conditions of the structures.

Thermotolerant Coliforms

Thermotolerant coliforms were detected in three samples: sample 6 (6 CFU/100 mL), sample 9 (2 CFU/100 mL), and sample 10 (145 CFU/100 mL). The concentrations of thermotolerant coliforms observed in this study are lower than those reported by [55], who found contamination levels reaching up to 1,000 CFU/100 mL in urban groundwater in the western Brazilian Amazon. Conversely, the results of this study are significantly higher than those obtained by [54] in their analysis of the microbiological quality of drinking water in the Gulf prefecture (Togo), where the maximum recorded concentration was 4 CFU/100 mL. These differences may be explained by variations in well depth, local environmental conditions, sanitation practices, and proximity to pollution sources.

Fecal Streptococci

The results obtained in this study show fecal streptococci concentrations lower than those reported by [51], who, in their evaluation of the bacteriological quality of well and borehole water in Lomé (Togo), observed values ranging from 0 to 20 CFU/100 mL. The data from this study are also well below those reported by [56] in their systematic review on factors influencing microbial contamination of groundwater, which recorded an average concentration of 9.4×10^3 CFU/100 mL. These differences may be attributed to contextual factors such as population density, level of urbanization, sanitation practices, and the protection status of the boreholes.

7. CONCLUSION

The assessment of the physico-chemical and microbiological quality of groundwater reveals a mixed situation. From a physico-chemical standpoint, the measured concentrations of pH, turbidity, conductivity, TDS, nitrates, nitrites, and iron generally comply with WHO guidelines. However, occasional anomalies—such as low pH values and elevated nitrate or iron levels—suggest anthropogenic influences, particularly linked to agricultural and mining activities.

In contrast, the microbiological analysis reveals worrying fecal contamination in 30% of the wells (E6, E9, and E10), with the detection of total coliforms, thermotolerant coliforms, and fecal streptococci. Sample E10 notably exceeds permissible limits, indicating a significant health risk that warrants urgent attention.

These results underscore the need to enhance well protection, implement regular water quality monitoring, and promote appropriate sanitation measures. To build on this study, it is recommended to broaden the scope of analysis to include other potential contaminants (such as heavy metals and pesticides), conduct seasonal evaluations, and develop local water treatment solutions adapted to the socio-environmental context of the study area.

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Declaration of Conflicts of Interest

The authors declare that they have no conflict of interest regarding the publication of this article.

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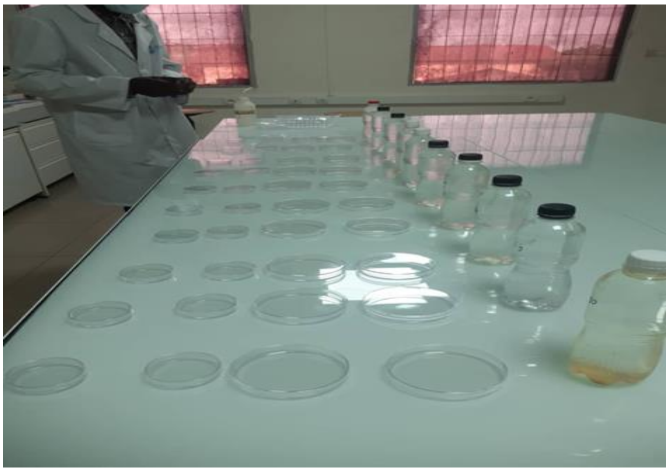
(Image a)

(Image b)

(Image c)



(Image d)

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