https://doi.org/10.48047/AFJBS.7.1.2025.391-411

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Microbiological quality assessment of well water in Bouake (Cote d'Ivoire): implications for public health and water safety

[1]Assanvo B. Justine*, [1]Konan K. Modeste [1]Die G. Romaric and [2]Bonny A. Carole

Corresponding author: Email: * justinebomo2015@gmail.com

[1]UFR Sciences et Technologies, Université Alassane OUATTARA, 01 BPV 18 01 Bouake, Côte d'Ivoire

[2]UFR Biosciences, UPR Biotechnologies, Université Félix Houphouët Boigny, Abidjan, Côte d'Ivoire, 22 BP 582 Abidjan 22

Author's contributions

This study was carried out in collaboration among all authors. Authors read and approved the manuscript.

Volume 7, Issue 1, Jan 2025
Received : 15 Nov 2024
Accepted : 20 Dec 2024
Published : 05 Jan 2025
Dio :10.48047/AFJBS.7.1.2025.391-411

ABSTRACT

Access to microbiologically safe drinking water remains a major challenge in improving people's living conditions. In Bouake (Central Côte d'Ivoire), good quality water is widely used for domestic purposes without adequate safety assurance. This study assessed the microbiological quality of 30 drinking water samples and examined associated health risks and household water management practices. The results revealed large contamination by faecal bacteria, particularly intestinal enterococci and *Escherichia coli*, at concentrations greatly exceeding regulatory standards. Other contaminants, such as total coliforms, *Pseudomonas aeruginosa* and sulphite-reducing *Clostridium*, were frequently detected, indicating recent and chronic faecal pollution. The household survey showed that an approximate 50 percent (49.33%) of the respondents consumed untreated drinking water. Waterborne diseases recorded were diarrhea (30%), helminth infections (15%), and typhoid fever (10%). Most wells were communal and widely used for domestic purposes. These results highlighted a major public health concern and an urgent need for interventions for improving water safety and promoting effective household water treatment practices.

Keywords: Well water contamination, *Escherichia coli*, waterborne diseases, faecal indicators, Bouake-Côte d'Ivoire.

INTRODUCTION

Access to drinking water is a fundamental right and a crucial issue for public health and sustainable development worldwide (**UN, 2018**). Despite the progress made in guaranteeing access to drinking water worldwide, more than 30% of the world's populace is still lacking access, particularly in developing countries. (**UNICEF, 2017**). In fact, drinking water quality borne diseases are of a major public health concern in many African cities, including Cote d'Ivoire (**RGPH, 2021; UNICEF and WHO, 2020**). Bouake, the second largest city of Cote d'Ivoire, is not exception to this problem, particularly regarding water supply. Although the city benefits from some drinking water supplies (SODECI, etc.), a large part of the population, living in the outlying districts and surrounding rural areas, continues to use water from wells. This dependence on wells exposes local populations to various risks related to water quality, with potentially serious public health consequences. Well water can be an important source of water which is not always free of contamination. According to the World Health Organization (**WHO, 2017**), water from untreated sources, such as wells, can be contaminated with pathogens, including fecal coliforms, protozoa and bacteria that cause diarrheal diseases. In Côte d'Ivoire, the quality of well water can be affected by environmental factors such as infiltration of wastewater, lack of sanitation and weak treatment before consumption (**UNICEF, 2021**). The city of Bouake has been grappling for several decades with major challenges in the provision of safe water. The water supply network managed by the Water Distribution Company of Côte d'Ivoire (SODECI) covers only a limited segment of the urban population (**SODECI, 2019**). The mili tary-political crisis that affected Côte d'Ivoire between 2002 and 2011 had a profound impact on public services, particularly in inland regions such as Bouake. During this period, the maintenance of public water infrastructure was severely neglected, and in some cases completely halted. The lack of regular maintenance, combined with the influx of internally displaced persons drinking into the city, resulted in a marked deterioration in the quality of distributed water and a widespread proliferation of unprotected wells as alternative water sources. This situation has exposed the population especially children and other vulnerable groups to increased microbiological risks. The aim of the study was to analyze the quality of well water consumed in the town of Bouake, assessing faecal coliforms, for formulating recommendations for safety of drinking water and the health of people.

The specific objectives are:

- Identify and map wells used for water consumption in the city of Bouaké.
- Assess microbiological contamination of water samples

METHODOLOGY

1. Sampling

1.1. Study area

Bouake is the second largest city of Côte d'Ivoire located in the Central part. The choice of this city was based on several criteria related to geographical diversity. The town comprises dense urban districts, suburban areas and rural zones. These different areas have distinct characteristics in terms of access to drinking water, with areas that are far from the drinking water network and those where there are supply problems relying in particular on wells.

1.2 Size of the population surveyed

The population size to be surveyed was determined using the sampling method proposed by **Cochran (1977)**, based on the following formula:

$$n = \frac{t^2 \, x[P x(1-P)]}{e^2}$$

Where:

n = minimum required sample size,

e = acceptable margin of error,

t = z-score corresponding to the desired confidence level,

p = estimated proportion of the population possessing the characteristic of interest.

For this study, the conventional parameter values used were:

e = 0.05; t = 1.96; p = 0.5

Using these values, the minimum sample size was estimated at 384.16. However, due to resource limitations of the study, the actual number of surveyed households was set at 150. For microbiological analysis, ten (10) districts (Assoumankro, Adjeyaokro, Ahougnanssou, Tchêlèkro, N'dakro, Broukro, Kôkô, Zone, Dar-es-salam, Belle-ville) were selected based on population density and the concentration of wells. In each district, three (3) wells were randomly selected. Water samples collected from these three wells were pooled to create a composite sample representative of the district. In total, thirty (30) wells were investigated, resulting in ten (10) composite samples subjected to microbiological analysis. The sampling campaign was conducted during the first two weeks of February 2025.

1.3 Survey

This survey was carried out to collect information on the quality of well water over a period of 3 to 5 months, the sources of supply, frequency and modes of use and the health impacts related to its consumption in the city of Bouake. For this purpose, qualitative and quantitative questionnaires were developed to serve as a basis for direct interviews with households, field observation and analysis of the quality of water sampled from various wells. The overall sample size is estimated at 150 households. The household is the basic survey sampling unit, obtained from a random drawing.

1.4 Sampling procedure

Sample collection is carried out rigorously to avoid any contamination. Hands are washed and gloves worn before each collection to avoid external contamination. For microbiological analysis, water samples were packaged in sterilized 500 ml sterile glass bottles. A blowtorch remains lit throughout the process to maintain the flame condition, preventing contamination of water samples by environmental germs at the time of collection and bottle closure. After collecting, samples were transported in refrigerated coolers at 4°C to prevent bacterial proliferation (for microbiological testing). In addition to low temperature storage, the packaging is hermetically sealed to prevent exposure to air and possible contamination of the samples.

2. Microbiological analysis

The microbiological analysis consisted of highlighting the presence of total mesophilic aerobic flora (TMAF), total coliforms and *Escherichia coli* and *Salmonella* spp.

2.1 Enumeration of total mesophilic aerobic flora (TMAF)

ISO 6222 (1999) describes the method for the determination of the total mesophilic aerobic flora in water samples. The method is based on the inoculation of a specific culture medium (Plate Count Agar (PCA). Water samples (1 mL) were transferred to the bottom of three sterile Petri dishes. After depositing the inoculum, approximately 15 ml of supercooled agar (45 to 50 °C) was poured into each Petri dish, carefully homogenized and allowed to solidify on a cold horizontal surface. Then 4 to 5 mL of white non-nutritive agar (agar 12 to 18 g/l distilled water, pH 7,0 at 25 °C) were added to the medium. After solidification, the dishes were incubated at 30 °C for 72 hours. For media interpretation, only plates containing between 30 and 300 colonies were retained for counting. The count was expressed as CFU (colony forming units) per sample volume (CFU/mL).

2.2 Enumeration of total Coliforms

Enumeration of total coliforms bacteria in water samples was performed according to **ISO 9308-1:2014**. One (1) mL of water sample, or decimal dilutions, was transferred to sterile Petri dishes. About 15 mL of VRBL agar, previously melted and brought to 44-47 °C, were added into the Petri dishes and allowed to solidify after homogenization. A second layer of VRBL agar (approximately 4 mL) was then added. After solidification, the inverted dishes were incubated at 30 °C for 24 hours (the temperature of 30 °C is optimal for the growth of total coliforms). For reading and interpretation of the media, only pink to red colonies with diameter greater than or equal to 0.5 mm with or without a zone of bile salt precipitation are considered typical coliform colonies. Plates containing between 15 and 150 colonies were considered for enumeration. Results were calculated as CFU (colony forming units) per sample volume (usually expressed as CFU/100 mL).

2.3 Enumeration of *Escherichia coli*

The **ISO 9308-1:2014** standard is based on culture of *E. coli* on a specific medium (MacConkey agar or EMB (eosin methylene blue) agar) and the detection of characteristic colonies after incubation at 44.5 °C ± 0.5 °C for 24 hours. The principle of the method is based on the biochemical properties of *E. coli*, including its ability to ferment lactose and produce acid and gas. The main steps of the method include filtration of the sample (membrane filter with a porosity of 0.45 µm), inoculation onto a selective medium and incubation. After incubation, the plates were examined to observe the presence of characteristic colonies of *E. coli*. On MacConkey agar, colonies fermenting lactose usually appear pink or red. The number of colonies was expressed in colony forming units (CFU) per sample volume (usually CFU/100 mL).

2.4 Detection of *Salmonella spp*.

The search protocol for *Salmonella spp*. in water samples was performed according to a method adapted from **NF ISO 6579-1: 2017**. A volume of 0.1L of water sample was filtered through a sterile membrane of 0.45 µm, which was then incubated in a pre-enrichment broth, such as peptone water at 37°C for 18 hours. After pre-enrichment, selective enrichment was performed in RVS (Rappaport-Vassiliadis-Soya Peptone) broth and incubated at 42°C for 24 hours. After enrichment, the cultures were streaked onto a selective agar plate (XLD agar). The media are incubated at an optimum temperature of 37°C for 24 hours. Presumption of Salmonella colonies (red with black center on XLD) were confirmed by urease and lysine decarboxylase tests. Results were reported as: presence or absence per 100 mL.

2.5 Enumeration of pathogenic *Staphylococci*

The enumeration of pathogenic *Staphylococci* in water samples was performed using a method adapted from the **ISO 6888-1:2021** standard. A 100 mL aliquot of each water sample was filtered through a sterile cellulose nitrate membrane filter (0.45 µm). The membrane was then placed into Baird-Parker agar, previously supplemented with egg yolk tellurite emulsion. Plates were incubated at 37 °C for 24 to 48 hours. Presumptive *Staphylococcus aureus* colonies were identified as black, shiny, convex, with a clear halo due to lecithinase activity. Suspect colonies were subcultured and confirmed by the coagulase test (rabbit plasma tube method). Results were expressed as colony-forming units per 100 mL of water (CFU/100 mL).

2.6 Enumeration of *Pseudomonas aeruginosa*

The enumeration of *Pseudomonas aeruginosa* was performed according to **ISO 16266:2006** standard. A 100 mL sample of water was filtered through a sterile membrane filter (0.45 µm). The membrane was placed on the surface of a selective medium: *Pseudomonas* CN (cetrimide-nalidixic acid) agar Bio-Rad. Incubation was performed at 37 °C for 45 hours. Typical *P. aeruginosa* colonies are greenish, fluorescent and may have a grape-like odour. Confirmation test includes a positive oxidase test.

2.7 Enumeration of intestinal *Enterococci*

Intestinal *Enterococci* enumeration was performed according to **ISO 7899-2:2000**, which specifies a membrane filtration method for detection of *Enterococci* in water samples. A measured volume (100 mL) of the water sample was filtered through a sterile pore-size membrane (0.45 µm). The membrane was then applied to Slanetz and Bartley agar plate. The plates were incubated at 37 °C for 44 hours. Colonies appearing red, chestnut brown, or pink were counted as presumptive *Enterococci*. For confirmation, plates were further tested by esculin hydrolysis in bile salt medium tests.

2.8 Detection and enumeration of sulfite-reducing anaerobic spores *Clostridium*

The enumeration of sulfite-reducing anaerobic spores was performed according to **ISO 6461-2:1986**. This method involves the selective recovery of *Clostridium* spores from water samples by membrane filtration. An amount of 100 mL of water sample was preheated at 80 °C for 10 minutes to eliminate vegetative cells. The treated sample was then filtred through a sterile membrane filter with a pore size of 0.2 µm. The membrane was placed on a selective agar medium containing iron and sulfite under strictly anaerobic conditions. The incubation was carried out at 37 °C for 48 hours. Sulfite-reducing *Clostridium* colonies resulting from the precipitation of iron sulfide. The results were expressed as the number of colony-forming units (CFU)/20 mL of sample.**Table 1: Summary of germs sought and standardized methods**

Parameters	Culture media	References
Revivable aerobic microorganisms at 22 °C (CFU/mL)	Standard nutrient agar (PCA)	ISO 6222:1999
Revivable aerobic microorganisms at 36 °C (CFU/mL)	Standard nutrient agar (PCA)	ISO 6222:1999
Total coliforms (CFU/100 mL)	VRBL agar	ISO 9308-1:2014
Thermotolerant coliforms (CFU/100 mL)	VRBL agar	ISO 9308-1:2014
***Escherichia coli* (CFU/100 mL)**	Chromogenic coliform agar	ISO 9308-1:2014
***Salmonella* spp. (Absent/100 mL)**	XLD agar and membrane filtration	ISO 6579-1:2017
Sulfite-reducing *Clostridium* (CFU/20 mL)	Gélose TSC (Tryptone-Sulfite-Cyclosérine)	ISO 6461-2:1986
***Pseudomonas aeruginosa* (CFU/100 mL)**	CN (Cetrimide-Nalidixic acid) Agar Bio-Rad	ISO 16266:2006
Intestinal enterococci (CFU/100 mL)	Slanetz and Bartley agar	ISO 7899-2:2000
Pathogenic Staphylococci (CFU/100 mL)	Chapman agar	ISO 6888-1:2021

3. Data analysis

The data collected was analyzed from the histograms obtained on the basis of the means and their standard deviations using the Excel 2013 analysis program. A one-way analysis of variance (ANOVA) of the means obtained was carried out using the SPSS Statistics software version 20.0 and the Duncan's test at the probability threshold (α = 0.05) is used to determine the significant differences between the means.

RESULTS

The results of the microbiological analysis of well water samples are presented in **table** 2. This assessment of 30 well water samples collected in Bouake revealed widespread non-compliance with the standards of the decree of 11 January 2007 regarding the quality limits for drinking water. Contamination by fecal indicator bacteria as *Escherichia coli* was systematically detected in all samples analyzed, with concentrations ranging from 86 to > 150 CFU/100 mL, largely above the regulatory limit of <1 CFU/100 mL. The presence of *E. coli* indicates a recent fecal contamination of the wells, posing a direct threat to public health due to the high risk of waterborne diseases transmission. Moreover, intestinal enterococci were detected at high levels, ranging from 41 to >150 CFU/100 mL. Their consistent presence reinforces the hypothesis of persistent fecal pollution, particularly considering their greater resistance to environmental conditions compared to *E. coli*. Total coliforms and thermotolerant coliforms (other indicators of microbial contamination) were consistently found at concentrations above 150 CFU/100 mL in all samples, indicating generalized organic pollution of well waters. *Pseudomonas aeruginosa* was variably detected, with counts reaching up to 46 CFU/100 mL in some samples. Although less consistently present, this opportunistic pathogen is a marker of degraded water quality and may pose a significant health risk, especially to immunocompromised individuals. Sulfite-reducing *Clostridium* species were detected across all samples, with concentrations ranging from 4 to 96 CFU/20 mL, exceeding the regulatory limits. The presence of these spores, which are resistant to extreme environmental conditions, suggests long-standing and chronic contamination. Overall microbial load: aerobic mesophilic bacteria count at both 22 °C and 36 °C consistently exceeded the limit of 20 CFU/mL, with all samples showing counts >300 CFU/mL. This finding reflects massive microbial contamination, likely facilitated by poor hygienic practices and the absence of physical protection structures around the wells. Absence of specific pathogens: it is noteworthy that *Salmonella spp*. was absent in all samples analyzed, and pathogenic *Staphylococci* remained below the regulatory thresholds in all cases. However, this absence does not mitigate the significance of the widespread fecal contamination observed.

Figure 1 presents photographs of some wells, which visually reflect their respective levels of microbial contamination.

Table 2: Enumeration results

Micro-organisms	Units	***Criteria**	**Samples (n = 30)** EP-BK-AS-M-0702251	EP-BK-AD-M-0702252	EP-BK-AH-M-0702253	EP-BK-TC-M-0702254	EP-BK-ND-M-0702255	EP-BK-BR-M-0702256	EP-BK-KO-M-0702257	EP-BK-ZO-M-0702258	EP-BK-DA-M-0702259	EP-BK-BE-M-07022510
E. coli	CFU/100 mL	**< 1**	90	112	> 150	86	> 150	100	95	135	> 150	> 150
Pathogenic *Staphylococci*	CFU/100 mL	**< 1**	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pseudomonas aeruginosa	CFU/100 mL	**< 1**	4	< 1	< 1	46	< 1	03	10	< 1	40	< 1
Intestinal *enterococci*	CFU/100 mL	**< 1**	65	> 150	124	94	41	> 150	140	50	90	> 150
Sulfite-reducing *Clostridium*	CFU/20 mL	**< 1**	4	23	96	28	12	8	20	90	30	15
Total coliforms	CFU/100 mL	**< 1**	> 150	> 150	> 150	> 150	> 150	> 150	> 150	> 150	> 150	> 150
Thermotolerant coliforms	CFU/100 mL	**< 1**	92	149	> 150	> 150	> 150	100	140	> 150	> 150	> 150
Revivable aerobic microorganisms at 22 °C	CFU/mL	**< 20**	> 300	> 300	> 300	> 300	> 300	> 300	> 300	> 300	> 300	> 300
Revivable aerobic microorganisms at 36 °C	CFU/mL	**< 20**	> 300	> 300	> 300	> 300	> 300	> 300	> 300	> 300	> 300	> 300
***Salmonella* spp.**	Abs/100 mL	**Abs**	Abs	Abs	Abs	Abs	Abs	Abs	Abs	Abs	Abs	Abs

***Criteria**: specifications (Decree of January 11, 2007 relating to the limits and quality standards for raw water and water intended for human consumption. Official Journal of the French Republic.)
n: number of samples analyzed. **Abs**: absent. **CFU**: colony-forming units.

Figure 1: Representative images of some wells

The pie chart **(Figure 2)** entitled "Health problems associated with well water use" shows significant health concerns among users. The most commonly reported health problem was diarrhea (30%), followed by helminth infections (15%), body itching (13%) and typhoid fever (10%). About 32% of respondents reported no symptoms, suggesting that a part of the population either used relatively safe water sources or had stronger immunity or resilience. The high prevalence of diarrhea highlights a critical indicator of microbial contamination, while the occurrence of helminth infections and typhoid fever strengthens the potential for fecal-oral transmission routes associated with untreated water of well. The bar and line graph **(Figure 3)** entitled 'Types of well water treatment prior to use' provides further information. A significant majority (approximately 49.33%) of respondents reported no treatment of well water before consumption, highlighting a huge risk factor for waterborne disease. Only a small proportion used boiling or filtration, while about 26% practiced only disinfection.

A small percentage combined boiling and disinfection (9.33%). The low uptake of boiling and filtration, both highly effective in removing pathogens, suggests either a lack of awareness, accessibility problems or socio-economic constraints.

In whole, these findings show a strong correlation between the lack of water treatment and the incidence of waterborne disease. The data highlights an urgent need for public health interventions, including awareness sensitization, improvements in safety water infrastructure and the promotion of effective household water treatment methods, to reduce the burden of well water-borne disease.

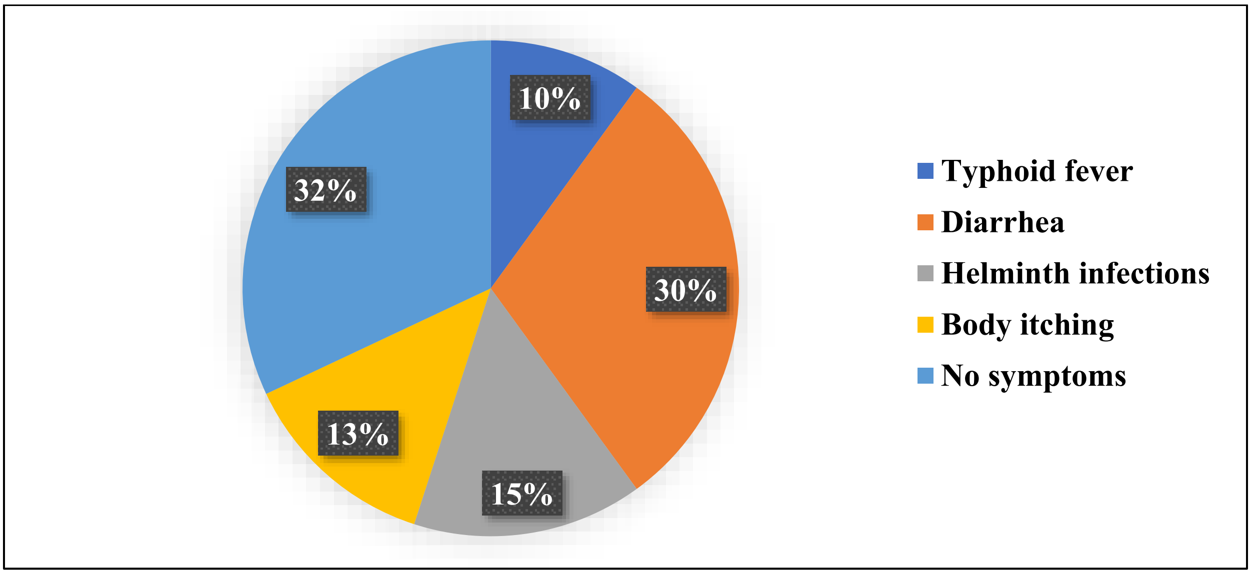

Figure 2: Health problems related to the use of well water

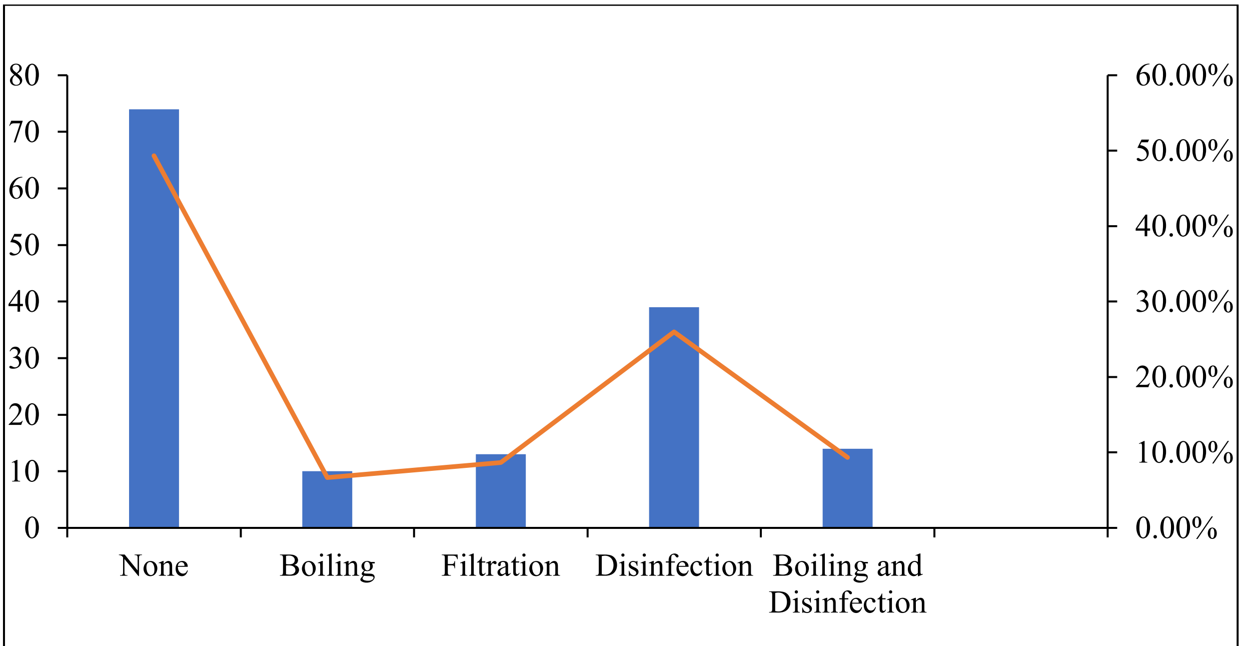

Figure 3: Types of treatments of well water prior to use

Figure 4 illustrates the different uses for well water. The data shows that most of respondents (75,34%) use water of well for all domestic activities (drinking, cooking, bathing, dishwashing, and laundry). A smaller proportion (17,33%) use this water specifically for dishwashing, laundry, and bathing, while a very small fraction (7,33%) restricts usage to dishwashing and laundry only. This indicates a heavy reliance on well water for daily household needs, reflecting its critical role in communities where alternative water sources may be limited or unreliable.

Figure 5 shows the distribution of types of wells. This result reveals that 85% of the wells are used communally, while only 15% are dedicated to private use. This predominance of communal wells highlights the collective management of water resources within the population. Such a distribution suggests that access to well water is largely organized on a shared basis, which may have implications for water quality control, maintenance practices, and potential contamination risks due to high user density.

Considering **Figures 3 and 4**, these findings underscore the vital role of well water in meeting the domestic needs of the studied population, as well as the importance of implementing appropriate water management and hygiene measures to ensure water safety, particularly in communal settings.

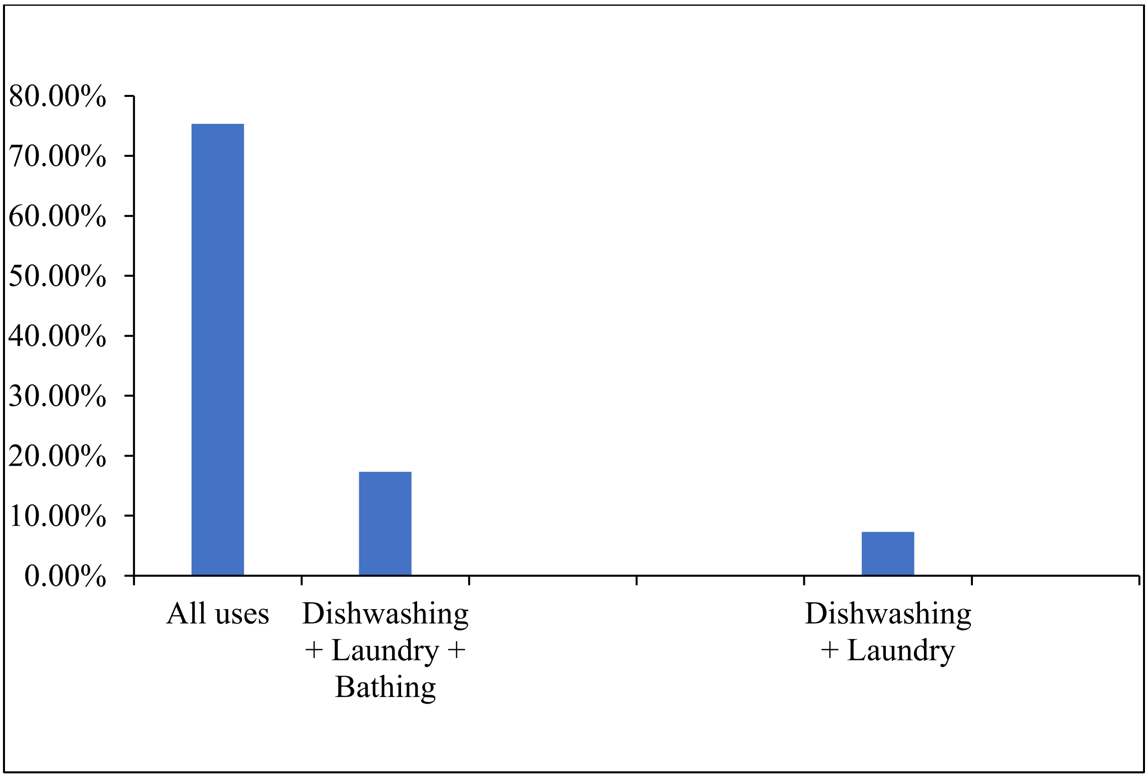

Figure 4: Distribution of the different types of well water used by the surveyed population

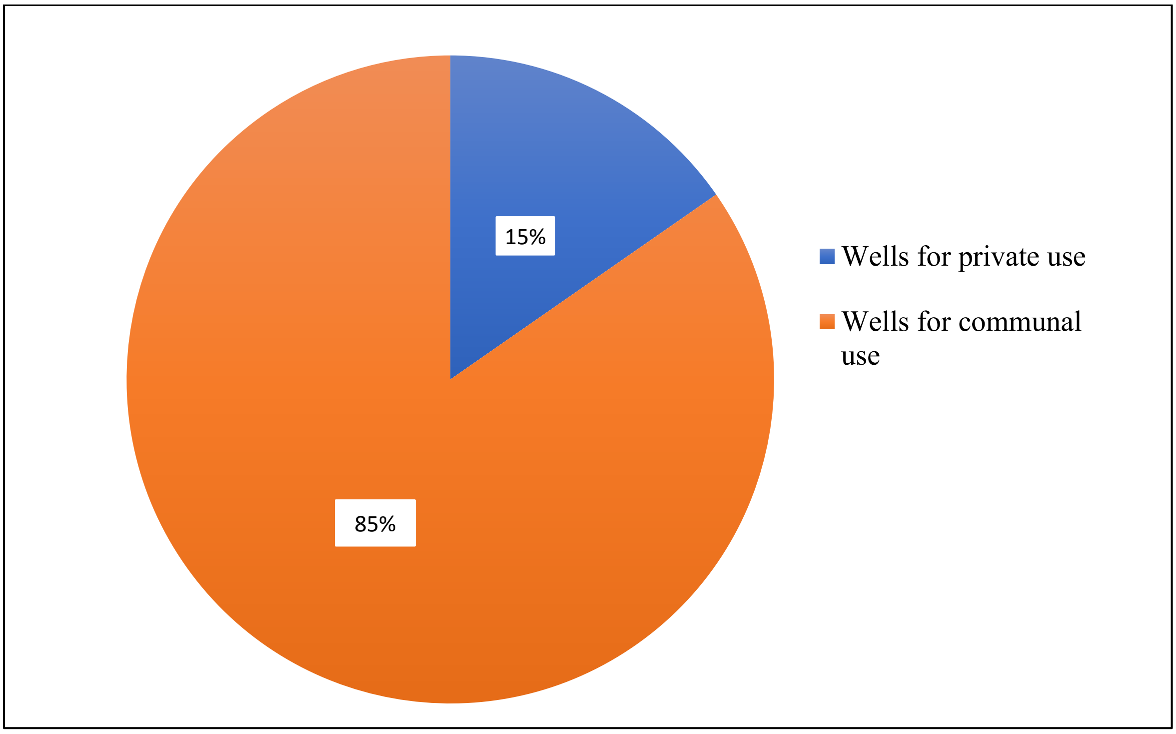

Figure 5: Proportion of wells according to their usage type (private vs. communal)

DISCUSSION

Microbiological analysis of well water samples from the city of Bouake has revealed serious contamination problems that raise major public health concerns. The systematic detection of *Escherichia coli* in all samples at concentrations ranging from 86 to >150 CFU/100 mL is alarming. According to the World Health Organization **(WHO, 2017)**, *E. coli* is a primary indicator of recent fecal contamination, that presence is an indicator of unsafe water for consumption. The high loads observed in this study far exceed the acceptable limit (<1 CFU/100 mL) and reflect significant fecal contamination, likely due to inadequate sanitation infrastructure, poor protection of water sources, and possible infiltration from nearby latrines or contaminated runoff, especially during rainy seasons.

Similarly, the high concentrations of intestinal enterococci (>150 CFU/100 mL in several samples) confirm the persistence of faecal contamination. Enterococci are known for their environmental resistance and are considered more reliable indicators of fecal contamination in tropical climates compared to *E. coli* **(Cabral, 2010)**. Their presence suggests both recent and chronic pollution of the wells.

The consistently high loads of total and thermotolerant coliforms (>150 CFU/100 mL) in all samples also indicated severe organic contamination. Total coliforms, while less specific in faecal pollution, reflect the overall hygiene conditions of water. The high levels observed in this study indicate long lasting microbial proliferation, likely exacerbated by poor well maintenance and exposure to surface contaminants.

The presence of *Pseudomonas aeruginosa* at concentrations up to 46 CFU/100 mL, is also important. *P. aeruginosa* is not a primary indicator of fecal contamination but an opportunistic pathogen that thrives in moist environments and can cause serious infections, particularly in immunocompromised individuals **(Mena and Gerba, 2009)**. Its detection reflects poor water quality and possible biofilm development in the well structures.

The detection of sulfite-reducing *Clostridium* species, with counts up to 96 CFU/20 mL, indicates a longstanding contamination. Clostridial spores are highly resistant to environmental stress and disinfection, and their presence is often associated with historical fecal pollution **(Payment and Franco, 1993)**. These results suggest that some wells have been chronically exposed to fecal contaminants over extended periods, without effective remediation.

In addition, the exceedingly high loads of aerobic mesophilic bacteria (>300 CFU/mL at both 22 °C and 36 °C) indicate massive microbial proliferation, that reveals highly unstable waters from a microbiological standpoint. Huge mesophilic counts are often associated with biofilm development, stagnant conditions, and nutrient-rich environments favoring bacterial growth.

Interestingly, *Salmonella spp*. and pathogenic staphylococci were absent from all samples, suggesting that while generalized fecal contamination is present, specific pathogenic species might not always be detectable, or could fluctuate seasonally or spatially.

Compared to similar studies conducted in West Africa **(Traoré *et al.*, 2016; Kouamé *et al.*, 2020)**, the level of contamination observed in Bouake wells appears particularly severe. These results are consistent with broader patterns reported in sub-Saharan Africa, where groundwater sources are increasingly threatened by urbanization, insufficient sanitation, and climate variability.

Overall, the findings underscore an urgent need for interventions aimed at improving water safety. Protective measures such as the building of sealed wellheads, routine disinfection, and community hygiene education are critical. In the long term, investment in improved sanitation infrastructure and sustainable water management practices will be essential to safeguard public health.

The health problems and water treatment practices associated with well water use highlight the significant public health risks associated with the use of untreated well water. The high prevalence of diarrhea among users is consistent with previous studies linking the consumption of microbiologically contaminated water to gastrointestinal infections **(WHO, 2017)**. Diarrheal diseases are often caused by pathogens such as *Escherichia coli*, *Shigella*, and *Vibrio cholerae*, which can thrive in poorly maintained water sources. In addition, the occurrence of helminth infections and typhoid fever underscores the likelihood of fecal contamination and poor hygiene practices associated with well management.

The relative high percentage of respondents reporting no symptoms suggests that not all wells may be equally contaminated, or that individual immune responses and past exposure may provide some protection. Nevertheless, the potential for asymptomatic carriers to perpetuate disease transmission cannot be overlooked.

The reported water treatment practices prior to use highlight significant gaps in water safety behaviors at the community level. The fact that approximately 49.33% of people use untreated water is alarming given the well-documented effectiveness of simple treatments such as boiling and filtration in eliminating waterborne pathogens **(Clasen *et al.*, 2007)**. The effectiveness of disinfection (35 % of users) depends heavily on the type of disinfectant used and the thoroughness of its application. These conditions are not always met in informal or resource-limited settings. These results highlight an urgent need for integrated interventions focused on improving water quality at the point of use. Public health strategies should prioritize community education on the risks associated with untreated water, promote affordable and sustainable household water treatment methods, and encourage regular monitoring and maintenance of well structures. In addition, policy frameworks must support infrastructure development to ensure safe water access, thereby reducing the burden of water-related diseases in affected communities.

The results obtained (about different types of well water use and proportion of wells according to their usage type) show a strong dependence of the studied population on well water for their domestic needs. About 80% of respondents reported using well water for all domestic activities, including drinking, cooking, bathing, dishwashing, and laundry. This finding underscores the critical role of well water as the main source of water supply and suggests a potentially increased exposure to health risks, especially if the microbiological quality of the water is not adequately monitored.

Moreover, the predominance of communal wells indicates a collective management of water resources. While this organization promotes broad access to water within the community, it also presents significant challenges in terms of well maintenance, contamination prevention, and the promotion of good hygiene practices. Indeed, a high number of users per well increases the risk of groundwater contamination and infrastructure degradation, particularly in the lack of effective community-based management mechanisms.

These observations call for the implementation of strategies to improve the quality of well water. Such measures could include water treatment initiatives, public awareness campaigns on safe water use practices, and programs for regular monitoring and rehabilitation of communal wells. The establishment of local water management committees may also provide a sustainable solution to ensure the safety and availability of this essential resource.

Finally, the low proportion of wells for private use could reflect inequalities in access to safer water sources or a collective approach to resource sharing. Further research is needed to better understand the underlying social and economic dynamics that influence water management practices within these communities.

The microbial profiles observed in water samples correspond closely to the main waterborne diseases reported in health facilities in Bouake, underscoring the role of unprotected wells as major vectors of transmission (**WHO, 2017**). According to regional health statistics (**Regional Health Directorate of Bouake, 2020**), waterborne diseases are among the top five causes of consultation in healthcare centers in the city. The Côte d'Ivoire Demographic and Health Survey (**INS-CI, 2018**) estimated the prevalence of acute diarrhea among children under five years at 18.1%, a rate strongly correlated with the consumption of contaminated water.

The microbiological contamination of well water is therefore a major source of waterborne disease in Bouake. Pathogenic bacteria frequently detected include *Escherichia coli*, pathogenic staphylococci, *Pseudomonas aeruginosa*, intestinal enterococci, sulfite-reducing clostridia, and total coliforms. These organisms are associated with a range of infections, particularly among children and immunocompromised individuals. Certain strains of *E. coli*, such as enterotoxigenic (ETEC) and enterohemorrhagic (EHEC) types, are responsible for severe infectious and hemorrhagic diarrheal diseases, which are commonly observed in children under five in the region of Bouake (**INSP, 2019**). According to **UNICEF (2020)**, diarrheal diseases account for more than 10% of infant mortality in Côte d'Ivoire, with peak incidence observed in central regions, including Bouake.

Pathogenic *Staphylococci* are known to produce heat-stable enterotoxins capable of causing foodborne intoxications, leading to symptoms such as vomiting, diarrhea, and abdominal cramps. Their presence in water is often linked to poor hand hygiene and inadequate handling of drinking water (**EPA, 2021**).

Pseudomonas aeruginosa can proliferate in poorly chlorinated water systems. It is associated with external otitis, skin infections, and respiratory illnesses, particularly in immunosuppressed individuals. Intestinal enterococci are capable of causing urinary tract infections, endocarditis, and intra-abdominal infections (**WHO, 2017**). Sulfite-reducing clostridia are implicated in mild foodborne illnesses, manifesting primarily as diarrhea and abdominal pain.

Although total coliforms are not always directly pathogenic, they are considered key indicators of fecal contamination and reflect a high risk of digestive infections, especially among children (**WHO, 2017**).

These conditions lead to serious public health consequences, including: an increase in cases of acute dehydration, particularly in children, school absenteeism and productivity losses in adults, and the overburdening of community health centers during hot or rainy seasons, when contamination rates are higher. Therefore, the implementation of improved water treatment systems, the protection of wells, and community education and awareness are essential measures to reduce the health risks associated with waterborne diseases in Bouake.

This study has several limitations that should be acknowledged. Its cross-sectional design does not capture potential seasonal variations in microbiological contamination, which are common in tropical regions. Health outcomes were based solely on self-reported data from households, without clinical or laboratory assessment, which may lead to recall bias or subjective 9interpretation. Although several microbial indicators were assessed, the study did not include testing for viral or protozoan pathogens, which may also be present and pose health risks. The analysis did not consider specific factors of well such as depth, proximity to pollution sources (e.g., latrines or livestock), or building materials, these conditions can influence water quality.

Despite these limitations, the study provides valuable insights into the microbial risks associated with well water consumption in Bouake. It underscores an urgent need for targeted public health interventions, including community education, low-cost water treatment solutions, and improvements in well construction and sanitation practices.

CONCLUSION

This study highlights the critical microbiological deterioration of well water quality in the city of Bouake. The systematic detection of fecal indicator bacteria such as *Escherichia coli* and intestinal enterococci, combined with consistently high loads of total coliforms, thermotolerant coliforms, sulfite-reducing *Clostridium* species, and aerobic mesophilic bacteria, demonstrates that most sampled wells are unsafe for human consumption without prior treatment. The findings point to a serious public health threat, particularly in communities that rely heavily on untreated groundwater for domestic use. Also, these results reflected in a broader context of poor sanitation, inadequate protection of water sources, and chronic environmental contamination. The correlation between microbial contamination and reported health issues such as diarrhea and typhoid fever underscores an urgent need for action.

Options for action include the implementation of community-based water safety programs, promoting household-level water treatment practices such as boiling and chlorination, and improving well building to prevent contamination. Public health authorities should prioritize awareness campaigns on the risks of untreated water and invest in sustainable sanitation infrastructure. Further research is warranted to monitor seasonal variations in contamination, assess the presence of viral and protozoan pathogens, and evaluate the long-term effectiveness of water safety interventions.

Ensuring access to microbiologically safe water is not only a public health imperative, but also a key component in achieving sustainable development goals related to health, water, and sanitation.

Conflict of interest

The authors do not have any conflicts of interest and have contributed to and approved the manuscript.

REFERENCES

Cabral, J.P.S. (2010). Water Microbiology: Bacterial Pathogens and Water. *International Journal of Environmental Research and Public Health*, 7:(10), 3657–3703. https://doi.org/10.3390/ijerph7103657

Clasen, T., Schmidt, W.-P., Rabie, T., Roberts, I., and Cairncross, S. (2007). Interventions to improve water quality for preventing diarrhoea: *Systematic review and meta-analysis*. BMJ, 334 : (7597), 782. https://doi.org/10.1136/bmj.39118.489931.BE

EPA (Environmental Protection Agency). (2021). Water and Health: Hygiene and Pathogen Transmission. Washington, DC, pp 1-45.

General Population and Housing Census (GPHC). (2021). National institute of statistics (INS) of Côte d'Ivoire, 300 p.

INS-CI (National Statistics Institute of Côte d'Ivoire). (2018). Demographic and health survey. Pp 1-356.

INSP (National Institute of Public Health of Côte d'Ivoire). (2019). National disease surveillance report. Pp 1-64.

International Organization for Standardization. (1999). ISO 6222: Water quality.

Enumeration of culturable micro-organisms. Colony count by inoculation in a nutrient agar culture medium.

International Organization for Standardization. (2014). ISO 9308-1: Water quality. Enumeration of Escherichia coli and coliform bacteria. Part 1: Membrane filtration method for waters with low bacterial background flora.

International Organization for Standardization. (2017). NF ISO 6579-1: Microbiology of the food chain. Horizontal method for the detection, enumeration and serotyping of *Salmonella*. Part 1: Detection of *Salmonella spp*.

International Organization for Standardization. (2021). ISO 6888-1: Microbiology of the food chain. Horizontal method for the enumeration of coagulase-positive *Staphylococci*. Part 1: Technique using Baird-Parker agar medium.

International Organization for Standardization. (2006). ISO 16266: Water quality. Detection and enumeration of *Pseudomonas aeruginosa*. Method by membrane filtration.

International Organization for Standardization. (2000). ISO 7899-2: Water quality. Detection and enumeration of intestinal *Enterococci*. Part 2: Membrane filtration method.

International Organization for Standardization. (1986). ISO 6461-2: Water quality. Detection and enumeration of the spores of sulfite-reducing anaerobes (*Clostridia*) — Part 2: Method by membrane filtration.

Kouamé, I. K., Kouassi, A. M., and Koffi, Y. B. (2020). Assessment of wells water quality and their suitability for drinking in M'Bahiakro City, Côte d'Ivoire. *Journal of Water Resource and Protection*, 12:(7), 567–581.

Mena, K.D., and Gerba, C.P. (2009). Risk Assessment of *Pseudomonas aeruginosa* in Water. *Reviews of Environmental Contamination and Toxicology*, 201, 71–115. https://doi.org/10.1007/978-1-4419-0032-6_3

Payment, P., and Franco, E. (1993). *Clostridium perfringens* and Somatic Coliphages as Indicators of the efficiency of drinking water treatment for viruses and protozoan cysts. *Applied and Environmental Microbiology*, 59:(8), 2418–2424.

Regional Health Directorate of Bouake. (2020). Annual Health Activity Report. Pp 1-72.

SODECI. (2019). Annual report on the state of drinking water supply in Côte d'Ivoire. Abidjan: SODECI, 116 p.

Traoré, S., Koné, D., Diakité, M., and Barry, A. (2016). Drastic vulnerability classification of Dabiss groundwater (Guinea). *Journal of Water Resources and Protection*, 8:(5), 479–490.

United Nations. (2018). The United nations world water development report 2018: Nature-based solutions for water. UNESCO. https://www.unwater.org/publications/world-water-development-report-2018

UNICEF. (2017). Safely managed drinking water: Thematic report on drinking water 2017. WHO/UNICEF Joint Monitoring Programme. https://data.unicef.org/wp content/uploads/2017/03/safely-managed-drinking-water-JMP-2017-1.pdf

UNICEF and World Health Organization. (2020). Progress on drinking water, sanitation and hygiene: 2000-2020. Fives years into the SDGs. Geneva: WHO and UNICEF. 121p.

UNICEF. (2021). Report on access to drinking water in West and Central Africa. New York: UNICEF. Retrieved from https://www.unicef.org/wca/fr/eau-assainissement-et-hygiene

UNICEF. (2020). Situation of Children in Côte d'Ivoire: National Report. Pp 1-88.

WHO (2017). Guidelines for drinking-water quality, 4th edition, incorporating the first addendum. World Health Organization, Geneva.