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Physico-Chemical and Microbiological Assessment of Borehole and Tap Water in Nzérékoré (Republic of Guinea)

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Abstract

The objective of this study is to assess the physico-chemical and microbiological quality of borehole and tap water consumed in the urban commune of Nzérékoré. The study was conducted from February 28 to October 13, 2024, and it is based on field surveys and laboratory analyses of 24 water samples from 14 boreholes and 10 randomly selected taps. Analyses were carried out in April, right at the start of the rainy season. We measured the fisico-chemical parameters (temperature, pH, electrical conductivity, turbidity, and total dissolved substances) in situ using a HI 9828 Hanna portable instrument. We measured the concentrations of chemical elements (aluminum, fluorine, chlorine, heavy metals, etc.) using titrimetry and atomic emission spectrometry. Bacterial contamination was determined by membrane filtration. The results show that the majority of borehole and tap water are compliant with WHO standards for concentrations of calcium, sodium, fluoride, carbonate, sulfate, phosphate and ammonium. However, anomalies were observed in temperature and, in some cases, pH, color, nitrates, iron and potassium. The pH of all water, whether from boreholes or taps, was acidic, with an average of 5.85 ± 0.048 for boreholes and 6.62 ± 0.42 for taps, which does not meet the standard of pH 6.5 - 8.5. Turbidity in tap water ranged from 0.01 to 10, with an average of 2.87 ± 0.58, and did not meet the WHO standard of 5 NTU in 20% of cases. Average levels of aluminum (0.664 ± 0.024 mg/l), lead (0.857 ± 0.06 mg/l), copper (3.139 ± 0.025 mg/l), and chromium (0.18 ± 0.034 mg/l) exceeded WHO standards of 0.2 mg/l, 0.01 mg/l, 2 mg/l, and 0.05 mg/l, respectively. Microbiological analyses show the absence of pathogenic germs in the tap water. However, one well is contaminated with thermotolerant coliforms and sulfur-reducing anaerobes (10 CFU/100 ml), while the WHO standard is 0 CFU/100 ml. The contamination of tap water with heavy metals and borehole water with fecal coliforms poses a health risk to the population. Urgent measures are needed to prevent the risk of waterborne diseases among consumers.

Keywords

Water Quality, Drinking Water, Public Health

1. Introduction

Water is an essential resource for all living beings. Water quality is a critical determinant of human health [1]. It is involved in many essential physiological functions, such as digestion, absorption, thermoregulation, and waste elimination [2]. Access to safe drinking water is a prerequisite for health, a basic human right, and a key component of effective health protection policies [3].

However, in 2022, 700 million people, or 9% of the world's population, will still lack access to drinking water (WHO, UNICEF). On the other hand, 5.8 billion people, or 73% of the world's population, have access to safe water, *i.e.* at home, at least twelve hours a day, and to uncontaminated water. The WHO adds that 1.5 billion people (18% of the world's population) have access to a drinking water source at least 30 minutes' walk from home.

It's a very arduous task, and it's usually done by women and girls. The WHO has confirmed that 80% of diseases worldwide are caused by a lack of drinking water and sanitation (p. 5, 2021). In Africa, Asia, and Latin America, an average of 75% of the population has no access to drinking water. The risk of water-borne diseases, such as diarrhea and cholera, is a major source of mortality worldwide [4]. Uncontrolled urbanization and population growth are limiting access to drinking water and sanitation. Pollution, disinfection treatments, and distribution network materials can introduce toxic molecules [5].

Guinea is the "water tower of West Africa", with 226 billion cubic meters of renewable water. However, the country suffers from a lack of access to drinking water due to structural problems such as insufficient infrastructure, the absence of a sustainable resource management plan, and inadequate pricing [6].

The Société d'Exploitation des Eaux de Guinée (SEG), a state-owned company responsible for exploiting natural water for human consumption in urban areas, and the Service National des Points d'Eau (SNAPE) in rural and semi-urban areas are unable to meet the population's drinking water needs.

In 2022, the rate of access to water services for Guineans was 31% in urban areas (40% in Conakry) and 26% in the country's other cities [7].

Geochemical alteration of silicates and anthropogenic input modify the hydrogeochemical facies of groundwater. Hydrolysis of natural silicates (feldspars, amphiboles, etc.) contributes dissolved ions such as sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), sodium hydroxide (NaOH), calcium carbonate

($CaCO_3$), and silica dioxide (SiO_2). Fertilizers used in agriculture and heavy metals from industry enrich the composition of groundwater with nitrates (NO_3^-), chlorine (Cl^-) and lead ($Pb2^+$) by dissolution. It is clear that groundwater composition in these different aquifers evolves according to water-rock interaction and internal mixing between the different groundwater flow paths in the lithological layers. Water quality is associated with drinking water standards and the chemical composition of major elements in groundwater [8].

Water quality is determined by the presence of various contaminants, both natural and human-made.

Consuming poor-quality water leads to water-borne diseases and poisoning from heavy metals and other toxic compounds. Water-related health risks are due to the presence of biological and chemical contaminants. Heavy metals like cadmium, aluminum, chromium, and nickel can contaminate tap water, causing various health problems, including cardiovascular disorders, kidney problems, neurocognitive effects, and cancer [9].

More than two million people, mostly children under the age of five, die every year from diarrhea in developing countries where hygiene and sanitation measures are inadequate [10].

Water intended for human consumption must be safe to drink. Water intended for human consumption is potable when it is free from chemical and biological elements likely to have short-, medium- or long-term effects on human health [11].

The urban commune of Nzérékoré relies mainly on boreholes and water distribution networks for its water supply. However, the quality of this water is not always documented. This raises concerns about their compliance with World Health Organization (WHO) standards.

The main objective of our work is to monitor the quality of tap and borehole water consumed in the urban commune of Nzérékoré, and to identify possible health risks.

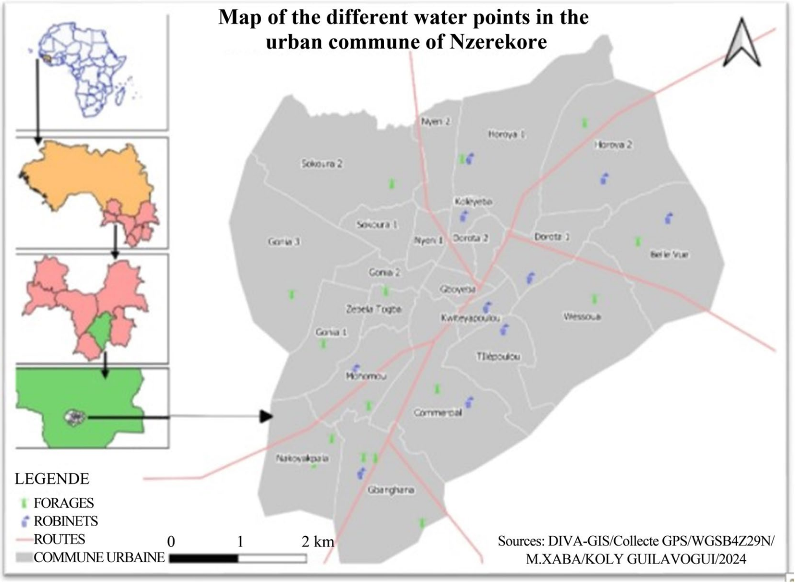
Several studies have been carried out to assess metallic pollution of surface waters and its impact on the marine environment, but data on the quality of tap and borehole water consumed by the population of Nzérékoré are scarce, as shown by the literature review. The present study is a contribution to the analysis of some quality parameters of water intended for human consumption. However, it is limited to sanitary control. Other aspects, such as pesticides, will be the subject of further studies.

2. Materials and Methods

2.1. Study Area: The Urban Commune of N'Nzérékoré

The urban commune of Nzérékoré (**Figure 1**) is the largest urban area in Guinée forestière and the capital of the administrative region of N'Nzérékoré. It is located in south-eastern Guinea. The town is 945 km from the capital, Conakry, and is built around the "Zalay" stream, hence its name.

Its precise location is between latitudes 7˚32 and 8˚22 north and longitudes 9˚04 and 9˚30 west. The urban commune is divided into 22 districts and 96 sectors. The Samoé rural district (CR) is to the north-west, the Bounouma CR is to the south, the Yalénzou CR is to the east, and Bounouma and Samoé are to the west. It covers an area of 47.4 km^2 with a population of 196,823, representing a density of 1744 inhabitants/km^2 (2014 census). This population has grown considerably, reaching 448,501 in 2018 (website: www.stat-guinee.org). The climate is subtropical, with two distinct seasons: a dry season from December to March and a rainy season from April to November. The Tilé River is the primary waterway that runs through the city [12].



Source: DIVA-GIS/Data GPS/WGSB4Z29N; Authors: Koly Guilavogui/Kaba Moussa.

Figure 1. The urban district of Nzérékoré.

2.2. Framework and Study Period

This work is an experimental, cross-sectional, and descriptive prospective study carried out in the commune of Nzérékoré. The project was carried out in the field from February to June 2024, a period of eight months.

The study was conducted at three locations: the analytical chemistry laboratory of the University of Nzérékoré, the SEG quality laboratory in Nzérékoré, and the regional water quality laboratory in Kankan. The objective was to assess the physicochemical and bacteriological quality of borehole and tap water consumed by the population of the urban commune of Nzérékoré.

2.3. Working Materials

This work was carried out using several pieces of equipment. We used a Garmin eTrex GPS (Global Positioning System) to geolocate the inventoried water points, and we used a camera to take images. We used 500 ml, 1 l, and 1.5 l propylene bottles to collect and transport samples. A compact Bluetooth turbidimeter was used to determine turbidity.

We used the HI 7500 photometer (HACH) to determine color, and the HI 98,194 waterproof multi-parameter, version 2015, to measure pH, temperature, electrical conductivity, and TDS. Coolers and carboglasses were used to store the samples.

The Agilent 4210 MP-AES (Microwave Plasma Atomic Emission Spectrometry) was used for heavy metal analysis.

The glassware included Petri dishes, 100-ml graduated test tubes, and test tubes. These tools are essential for precise volume measurements and mixing solutions.

A variety of equipment was used, including forceps, pasteur pipettes, graduated pipettes, beakers, and analytical balances accurate to 0.01 grams, as well as a drying oven. They were used for handling, weighing, preparing, sampling, and mixing solutions.

The equipment included an autoclave, a Bunsen burner, ovens set at 37˚C and 44˚C, sterilization equipment, and a Wagtech incubator programmed at 37 ± 1˚C and 44 ± 1˚C for the determination of total and fecal coliforms.

Statistica, Excel, ArcGis, and Piper diagram software were used for data analysis and processing. Microsoft Excel version 2016 was used to process and analyze numerical data and produce graphical representations.

2.4. Method

2.4.1. L'échantillonnage [13] [14]

Sampling followed the protocols outlined in Afnor FD T90-523 (Afnor, 2008) and NF EN ISO 19458 (November 2006), employing simple random selection. The sample must be homogeneous and representative, and it must not alter the physico-chemical and microbiological characteristics of the water.

The sampling method is clear: eight of the 22 districts have no Société de l'eau de Guinée (SEG) distribution network facilities. Four were completely disconnected from the system by road rehabilitation work undertaken by the mayor, and eight received water once a week [15]: The current status of the drinking water supply in the urban commune of N'Zerekoré is as follows: The clientele of the centers in the interior is managed by the Direction Clientèle des centres de l'intérieur, and the Direction régionale de la Guinée forestière oversees the regional centers. In 2024, we inventoried 55 boreholes in the commune, 15 of which are out of order.

A total of 24 water samples were collected from 14 boreholes and 10 taps, considering logistical, financial, and time limitations. the selection criterion is usage. The selection criterion is usage. Acceptable representativeness was ensured by randomly selecting and geographically distributing sampling points to cover the main areas of the commune. This included densely populated neighborhoods, peripheral areas served by taps or boreholes, areas accessible to springs, and those with high population density and frequentation.

Then, all the selected water points were geo-referenced to show their spatial distribution in the town of Nzérékoré. The sampling points and their exact locations are shown in Table 1 below.

Reference of sampled boreholes and taps:

Table 1. Location of borehole and tap water sampling points.

N˚	Neighborhoods	Boreholes		N˚	Neighborhoods	Taps	
		N(+)	**W(−)**			**N(+)**	**W(−)**
1	belle vue	7.453430	8.474572	1	belle vue s4	7.7666655	8.797530
2	Mohomou	7.4456180	8.492815	2	Horoya 2	7.44532327	8.4965901
3	Nakoyakpala	7.730113	8.835735	3	Commercial	7.44532327	8.4965901
4	Horoya 1	7.4659402	8.484070	**4**	Dorota 2	7.44532327	8.4965901
5	Horoya 2	7.756545	8.481239	**5**	Gbanghana	7.73092422	8.8291475
6	commecial	7.739685	8.819423	6	Nzebela Tokpa	7.74551607	8.8344458
7	Dorota 2	7.45706	8.47969	7	Nyen2	7.76601415	8.8254127
8	Gbanghana	7.730811	8.827582	8	Mohomou	7.44217332	8.833256
9	Nzebela Tokpa	7.748877	8.824488	9	Tilepoulou	7.747318	8.810722
10	Nyen2	7.765639	8.819721	10	Kouiteapoulou	7.750160	8.812998
11	Nyen 1	7.769446	8.830618				
12	Mohomou	7.738139	8.831646				
13	Gonia 2	7.823660	8.835633				
14	Gonia 3	7.722238	8.835016				

N: Latitude; W: Longitude in decimal degrees.

The sampling technique and sample preservation are critical.

Taps were disinfected with an alcohol solution prior to sampling, then the tap spout was flamed using a clean iron bar wrapped in cotton and inhibited with 95% alcohol. Water was run for 2 - 3 minutes to flush out deposits in the piping.

Sterilized 1.5-L and 1-L vials were used for filling. These vials were thoroughly washed and rinsed three times with distilled water. As a precaution (wearing gloves, etc.), the bottles were rinsed three times with the water to be sampled before filling.

For cation determination, the water was acidified with nitric acid (by adding 0.5 ml of a 50% (v/v) HNO_3 solution per 125 ml) as soon as it was sampled, to a pH of 1.5. Then, it was resealed with cotton wadding and numbered. During collection, the opening of the bottle must not touch the spout of the tap. For chlorine-treated water, sodium thiosulfate was added to every 200 ml of sample. Four or five drops of liquid sodium thiosulfate solution (100 g/l) were added to each container of clean, sterilized sample. This immediately deactivated any residual chlorine. The samples were labeled and stored in a cooler with ice packs at a temperature between 4 and 6˚C during transport to the laboratory [14].

The vials were filled to the brim and tightly capped to prevent splashing and air intrusion on closure. All samples were labeled and transported to the laboratory in a cool box. The interval between sample collection and the start of analysis was no more than 8 hours for microbiological analysis and 2 days for heavy metal analysis.

The water samples were transported to the Kankan regional water quality laboratory for heavy metal analysis the day after sampling.

2.4.2. Analysis

Chlorides, calcium, magnesium, bicarbonates, total hardness, and alkalinity were measured by titrimetry. Ammonium, nitrates, nitrites, sulfates, and fluorides were determined photometrically. The methods recommended by [14] were used for all determinations. Turbidity was determined by nephelometry using an HI 7500 integrated turbidimeter, and color by photometry using a HACH HI 7500 photometer. The membrane filtration method described in [14] was used to count the total and fecal coliforms.

Heavy metals (zinc, cobalt, nickel, cadmium, lead, and mercury) were analyzed by MP-AES (Microwave Plasma Atomic Emission Spectrometry), an Agilent 4210 process offering high sensitivity and detection limits below ppb, and faster than conventional flame atomic absorption.

The detection limit is 0 - 5 mg/l. Use a microwave plasma atomic emission spectrophotometer to measure it.

3. Results and Discussion

The methodology was applied, leading to the results presented in the table and figures below. These results were interpreted and discussed according to the available literature data.

Following **Figure 2** is the physico-chemical parameters:

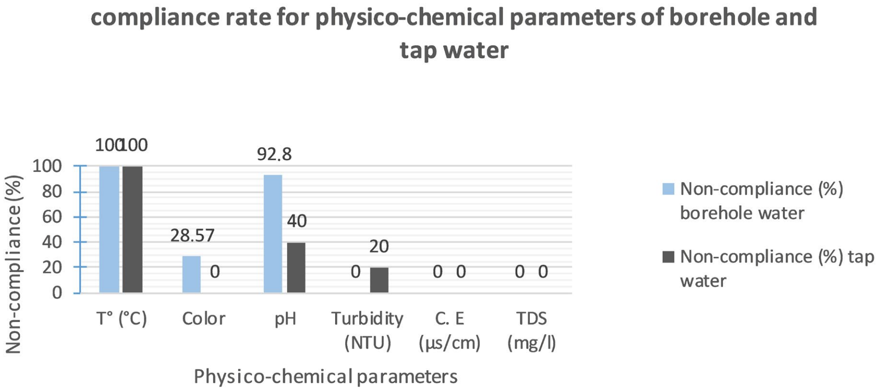


Figure 2. Compliance rate induced by physico-chemical parameters of borehole and tap water.

The average temperature of borehole and tap water is 28.31 ± 0.97˚C and 29.80 ± 1.1˚C, respectively. The temperature range for wells is from 26.86 to 30.18˚C, and for boreholes, it's from 27.85 to 31.5˚C. The WHO standard of 25˚C was not met by the well and tap water samples. These results are consistent with those of the study [16]. Water temperature does not directly impact health. The slight difference of 0.89˚C for boreholes and 2.42˚C for taps is explained by climate, the study season [17] and the shallow origin of the groundwater [14].

The pH of all borehole and tap water analyzed was acidic, with an average of 5.85 ± 0.048 for boreholes and 6.62 ± 0.42 for taps. It's clear that these results are similar to those of [14] and [18]. pH depends on soil type [19].

Turbidity in borehole water ranges from 0.01 to 4.96 NTU, with an average of 0.84 ± 0.27 NTU. Turbidity of tap water ranged from 0.01 to 10, with an average of 2.87 ± 0.58. Turbidity in borehole water complies with the WHO standard of 5 NTU. Furthermore, 20% of tap water complies with this standard. These values are close to those of [16].

Conductivity ranges from 67 to 645.3 µS/cm for boreholes and from 56 to 137 µS/cm for taps. Total dissolved solids levels (33 to 326 mg/l) in borehole and tap water samples comply with WHO standards. The measurements are less than 1000 µS/cm and 600 mg/l.

The results are similar to those obtained by [15], but lower than those found by this author (295.33 µS/cm). The high deviation clearly indicates very heterogeneous mineralization. The difference in conductivity is due to the nature of the hydraulic soil. Total dissolved substance values range from 9 to 462 mg/l, with an average of 140.41 ± 20.05, and are similar to those found by [18].

Chemical parameters:

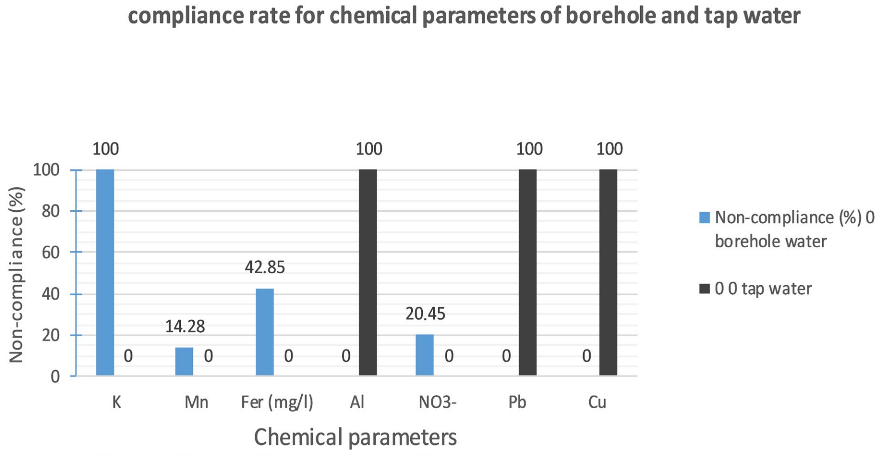


Figure 3. The non-compliance rates for chemical parameters in borehole and tap water are clear.

The average levels of aluminum (0.664 ± 0.024 mg/l), lead (0.857 ± 0.06 mg/l), copper (3.139 ± 0.025 mg/l), and chromium (0.18 ± 0.034 mg/l) exceed the WHO standards set at 0.2 mg/l, 0.01 mg/l, 2 mg/l, and 0.05 mg/l, respectively. However, it contains no traces of arsenic, cadmium, or nickel.

Tap water is treated, but it still contains high concentrations of heavy metals due to the corrosion of old pipes.

Heavy metals like lead, copper, iron, zinc, and cadmium are present in tap water. They come from the raw water, metal salts added during treatment, and water distribution pipe materials that are corroded due to solubilization corrosion phenomena [20] [21].

Borehole water complies with nitrate standards in only 20.45% of cases due to geological conditions, human activities (agriculture and industry), and the state of the boreholes. They are not compliant for potassium (100%), manganese (14.28%), and iron (42.85%) (**Figure 3**).

On the other hand, both borehole and tap water comply with WHO standards for calcium, chloride, sodium, nitrite, nitrate, ammonium and phosphate [22].

Piper diagram:

The Piper diagram (**Figure 4**) was analyzed using LHA software (Laboratoire hydrochimie d'Avignon v6). 77) Our analysis of major element data (anions: HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, PO_4^-) and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) allowed us to identify three distinct groups of groundwater chemical facies in the urban commune of Nzérékoré.

- The calcic and magnesian bicarbonate facies are made up of borehole waters (F1, F3, F7, F8, and F10). These waters are soft and poorly mineralized. They are generally of natural origin and suitable for consumption.
- The chloride and sodium sulfate facies in some borehole waters (F5, F6, F9, F11) in the zone indicate significant mineralization.
- Sodium and/or potassium chloride and sulphate facies are present in the more mineralized borehole waters (F4, F13, F14). These waters show a clear tendency towards a mixed facies (sodium bicarbonate or calcium chloride). This suggests that there are mixing processes between several groundwater sources.
- Sodium potassium bicarbonate facies (F2, F12) clearly indicate the influence of silicate rock dissolution processes.

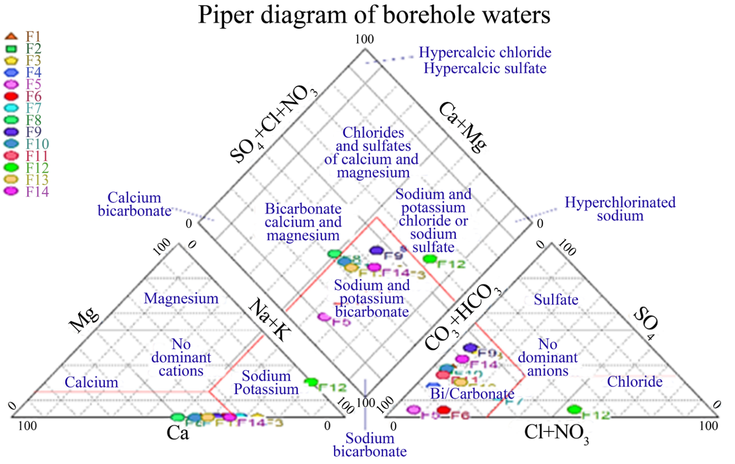


Figure 4. Piper diagram for borehole water.

Microbiological parameters:

The results of the microbiological analyses definitively showed that the taps were free of the microbial germs of interest (**Figure 5**). Boreholes showed a non-compliance rate of 7.14% for CTT and sulphur-reducing anaerobes. The presence of fecal coliforms, also known as thermotolerant coliforms, indicates fecal contamination. This means that there is a probable risk of pathogenic germs being present in these waters. Their presence is dangerous to health [22]. These results are consistent with those reported in [23].

Table 2. Borehole and tap compliance table.

	Parameters	**WHO standards**	Boreholes			Tap		
			Average	Standard-deviation	C (%)	**Average**	Standard-deviation	C (%)
Physico-chemical	T° (°)	**25**	28.31	0.97	0	29.803	1.115	0
	Turb (NTU)	**<5**	0.84	1.27	100	2.879	3.585	80
	Neck (UCV)	**<15**	13.6	5.89	71	12.3	1.345	71.43
	pH	**6.5 - 8.5**	5.85	0.48	97.73	6.619	0.423	7.2
	EC (µs/cm)	**<1200**	167.44	143.74	100	90.82	26.388	100
	TDS (mg/l)	**<500**	84.33	72.90	100	86.266	46.857	100
Chemical	Ca (mg/l)	**50 - 75**	28.82	16.64	100	34.38	1.74	100
	Na (mg/l)	**200**	93.85	42.84	100	43.25	4.65	100
	Mg (mg/l)	**5**	3.93	2.32	**100**	0.02	0.007	100
	K (mg/l)	**12**	22.87	1.62	0	27.37	0.685	100
	Mn (mg/l)	**0.4**	0.21	0.23	85.72	0.07	0.01	100
	Iron (mg/l)	**0.3 - 0.5**	0.06	0.015	71.5	0.14	0.007	100
	Al (mg/l)	**0.2**	0.04	0.042	100	0.664	0.025	0
	F^- (mg/l)	**0.7 - 1.5**	0.05	0.005	100	0.88	0.012	100
	HCO_3^- (mg/l)	**<500**	93.85	42.84	100	100.5	4.1	100
	SO_4^{2-} (mg/l)	**250**	74.8	53.96	100	99.9	3.1	100
	Cl^- (mg/l)	**250**	37.44	34.88	100	14.6	3	100
	PO_4^{3-} (mg/l)	**5**	0.16	0.05	100	0.14	0.025	100
	NH_4^+ (mg/l)	**0.5**	0.08	0.05	100	0.04	0.0335	100
	NO_3^- (mg/l)	**50**	2.87	1.62	100	1.6	0.2	100
	NO_2^-	**3**	0.06	0.015	100	0.035	0.005	100
Heavy metals	Pb (mg/l)	**0.01**	-	-	-	0.857	0.060	0
	Cu (mg/l)	**2**	-	-	-	3.139	0.025	0
	Cd (mg/l)	**0.003**	-	-	-	0	0	100
	Ni (mg/l)	**0**	-	-	-	0	0.034	100
	As (mg/l)	**0.01**	-	-	-	0	0	100
	Cr (mg/l)	**0.05**	-		-	0.18	0	0
Microbiological	FMAT (CFU)	**0**	1	3	92.85	0	0	100
	CT (CFU)	**0**	1	3	92.85	0	0	100
	CF (CFU)	**0**	1	3	92.85	0	0	100
	ASR (CFU)	**0**	0.5	1.5	92.85	0	0	100

C (%): percentage compliance; (-): not assessed.

Results of measured parameters, standard deviations and WHO standards are summarized in Table 2.

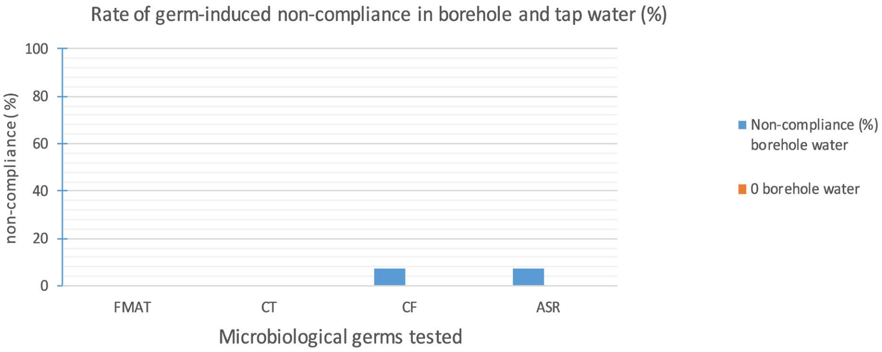


Figure 5. Non-compliance rate for microbiological germs in borehole and tap water.

The comparative statistical analysis of compliance rates between taps and boreholes is clear.

Table 3. Standard deviations of compliance rates between taps and boreholes.

Sample type	Average (%)
boreholes	88.64
tap	70.69

The average standard deviation of compliance rates for taps is higher. The data are more dispersed and less homogeneous than those from boreholes, reflecting a high degree of variability in their quality. Borehole water has a higher compliance rate than tap water (Table 3).

4. Conclusions

The chemical quality of borehole water is better than that of tap water. Taps show several cases of heavy metal contamination, probably linked to distribution materials or local anthropogenic sources.

The tap water in the urban commune of Nzérékoré is subject to heavy metal pollution, with levels that far exceed WHO standards. The pollution is primarily due to the dilapidated state of the installations, which are made up of galvanized iron pipes, and are in a state of corrosion. Treatment is another contributing factor.

5. Outlook

The authorities must take immediate action in response to these findings. They must inform the population of the health risks associated with consuming these non-potable waters.

It is imperative that they contribute to solving the problems of drinking water supply and environmental sanitation in the long term.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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