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PHYSICO-CHEMICAL AND BACTERIOLOGICAL CHARACTERISATION OF DRINKING WATER FOR THE POPULATION IN THE MUNICIPALITY OF KASSA, CONAKRY, REPUBLIC OF GUINEA

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ABSTRACT

The shortage of drinking water in the municipality of Kassa is affecting the way of life and health of its residents, thereby posing a major public health challenge.

The aim of this study is to determine the potability of the water used by the island's population through physico-chemical and bacteriological analyses.

A direct survey of potential sources of pollution was carried out in ten areas of the municipality, followed by sampling from thirteen wells, two boreholes and one spring. The samples were analysed on site and in the laboratory during the dry and wet seasons of 2024.

The analyses reveal that 68.13 per cent of water sources have physical problems, 64.58 per cent are chemically polluted and 42.71 per cent are affected by bacteriological problems.

These findings confirm that the shortage of drinking water in Kassa is a major issue for public health and community wellbeing, requiring targeted measures to improve the quality of water intended for consumption.

Keywords: Assessment, Quality, Drinking water, Kassa.

1 INTRODUCTION

Guinea, a coastal country in West Africa, is home to its capital, Conakry, which is spread across the Kaloum Peninsula and the Loos Islands – our study area [1].

Nicknamed the ‘water tower of West Africa’, Guinea nevertheless continues to be characterised by limited access to drinking water for its population: a supply rate of 67.8 per cent in 2012 [2], and only 40 per cent of Conakry’s population was supplied by the SEG in 2020, with the municipality of Kassa having no water supply facilities at all [3].

Yet water is fundamental to health, human dignity and development, in line with the Millennium Development Goals [4]. Despite efforts to manage water resources, island communities continue to be largely overlooked when it comes to waterborne diseases. The Loos Islands rely on traditional wells, seasonal watercourses, a few boreholes and imported water sachets, the supply of which is dwindling due to population growth and the overexploitation of groundwater reserves [5].

The quality of these waters depends on geology, human activities and marine intrusion [6], [7], with salinisation being a major cause of degradation in island areas [8].

This study therefore assesses the quality of drinking water in Kassa based on its physicochemical and bacteriological parameters.

2 MATERIALS

The municipality of Kassa, situated off the coast of Boulbinet, lies between 9°27'15’“north latitude and 13°47'24”' west longitude (see Figure 1). Covering an area of 60 km² (with a diameter of 18 km), it is 7 km (Kassa) and 13 km (Fotoba) from Conakry, and comprises ten neighbourhoods [9].

According to [10], water is a unifying resource that is essential to living organisms and ecosystems. It is estimated to total approximately 1,400,000 km³ globally, of which 2.5 %, is fresh water [11]. It is distributed amongst the oceans (97.2 %), polar ice (2.15 %), inland waters (0.649 %) and the atmosphere (0.001 %) [12], with the exchange between them regulated by the hydrological cycle.

Around 2.1 billion people (30 % of the world’s population) do not have access to safe drinking water [13]. The quality of aquifers is deteriorating significantly due to industrial discharges, chemical fertilisers and the unregulated exploitation of resources [14; 15; 16].

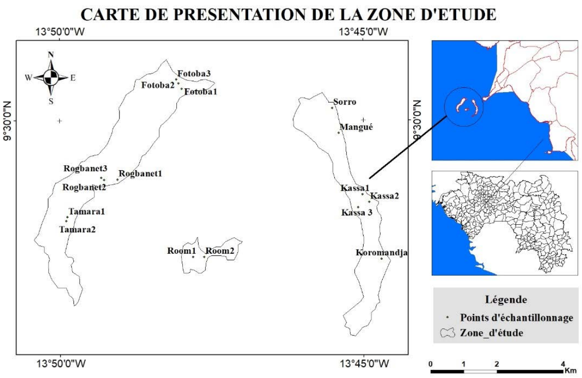

Figure 1*:* Presentation of the study area

3 METHODS

3.1 Field observation

To identify potential sources of well water pollution in the various sectors of the municipality of Kassa, a systematic approach was adopted. Statistical reports on water points, provided by the mayor and the sector heads, enabled the most frequently used water points to be identified. According to [17], content analysis enables previous data to be reused to meet research objectives ; this data has helped to identify water sources at risk. A direct observation of the surroundings of the structures, carried out using a dedicated checklist, enabled the identification of sources of pollution linked to human activities: latrines, laundry, vegetable gardens, rubbish dumps and marine intrusion. The data collected were entered and processed using Microsoft Word, which, according to [18], ensures rigorous management of the information.

3.2 Sampling

This study was carried out in two phases: a field phase and a laboratory phase. The first phase involved descriptive observation, manual sampling and in situ analyses, whilst the second phase focused on the preparation of samples and instruments, followed by physico-chemical and bacteriological analyses.

A targeted sampling method was applied, focusing on water sources likely to contain contaminants, selected to represent all the groundwater bodies in the municipality of Kassa (see Figure 1 above). A total of 32 samples were collected from the three inhabited islands (Kassa, Tamara and Room): 16 in April–May 2024 (dry season) and 16 in July–August 2024 (rainy season). The samples were collected in one-litre propylene bottles, which were sterilised and rinsed three times prior to sampling.

Following the on-site analyses, the samples were labelled and stored at 4 °C, then transported to the laboratory of the Guinean Institute for Environmental Research (IREG) within 48 hours for the remaining analyses, in accordance with the recommendations in [19].

3.3 Sample analysis

L'analyse des échantillons d'eau a suivi des procédures rigoureuses de prélèvement, de conservation et d'analyse, garantissant ainsi la fiabilité des résultats. Un protocole précis a été élaboré pour déterminer le degré de potabilité de l'eau de consommation dans les différents secteurs de la commune de Kassa. Certains paramètres (température, pH, conductivité électrique, TDS, salinité et OD) ont été mesurés sur place, tandis que la turbidité, les matières en suspension (MES), le fer total, les sulfates, les phosphates, les nitrates, les nitrites et les paramètres bactériologiques (coliformes totaux, coliformes fécaux et streptocoques fécaux) ont été analysés au laboratoire de l'IREG. Les résultats des deux saisons ont été comparés à la norme OMS 2016. Selon [19] et [20], chaque paramètre a été analysé selon une méthode spécifique : spectrophotométrie, réduction au cadmium, méthode amino-acide, statistique et filtration sur membrane Millipore (0,45 µm).

The analytical protocols followed comply with the methodological standards of the American Public Health Association (APHA) and the validated procedures of HACH. The equipment used for the analyses includes:

- a HACH DR/850 spectrophotometer for determining chemical parameters such as: nitrates and nitrites (uncertainty ±0.1), sulphate (uncertainty ±0.03), phosphates, etc.;
- a 70+ WATERPROOF pH meter for measuring pH (uncertainty ±0.1), temperature (uncertainty ±0.1), total dissolved solids (uncertainty ±0.1) and suspended solids (uncertainty ±0.025);
- a 70+ WATERPROOF conductivity meter for conductivity (uncertainty ±4);
- a Lovibond TB210IR turbidity meter for measuring turbidity (uncertainty ±0.025);
- CL011 and DelAgua-2000 incubators for incubating culture media in microbiological analyses (uncertainty ±0.001).

These methods ensure that the results are reliable, reproducible and comply with the WHO's requirements for the quality control of water intended for human consumption.

Consequently, Excel and OriginPro 9.0 64-bit were used to process the data obtained following analysis of the parameters under study.

3.4 Calculation of contamination levels in water samples

To calculate the average values of the various parameters, the following formula was used:

$Moy = \frac{X1+X2+\cdots+Xn}{N}$; [21].

X: represents the individual result for each parameter at each water point,

N: is the total number of wells; here, N = 16 sampling points.

The following formula was used to calculate the contamination rates of the water samples analysed:

$$P = \frac{\text{Number of contaminated well water samples}}{\text{Total number of water samples}}\text{ ; [21].}$$

4 RESULTS

4.1 Field observation

Following our investigations in the areas studied, it was found that, of the sixteen (16) water points surveyed, some were found to be sources of pollution.

4.1.1 Latrines / laundry area

Latrines and laundry areas, situated between 2 and 70 metres from the wells, were observed near several wells, notably at Rogbanè 1, Tamara 1, Room 1, Sorro, Mangué, Kassa 1 and Kassa 3 (see Table 1). Water from latrines and laundry areas is a source of pollution for nearby wells.

Table 1: Statistics on the distances between latrines and wells (in metres) in the municipality of Kassa.

Distance between latrine and well (in metres)	Number of wells	Percentage (%)
0 à 15	7	43,75%
15 à 30	5	31,25%
30 à 45	2	12,50%
45 à 60	1	6,25%
> 60	1	6,25%
Total	**16**	**100%**

The latrines are situated at distances ranging from 2 to 15 metres from 7 of the 16 sampling points (Rogbanè 1, Tamara 2, Room 1, Sorro, Mangué, Kassa 1 and Kassa 3), which significantly contributes to the pollution of the water in these wells. The proximity of these unimproved latrines and laundry areas to water points increases the risk of contamination from wastewater. Furthermore, some of these wells are also unimproved, which further increases vulnerability.

4.1.2 Rubbish tip and vegetable garden

Rubbish dumps and vegetable gardens, situated between 2 and 120 metres from water points, were observed at all 16 sampling sites (see Table 2). This proximity poses a threat to the quality of drinking water in the municipality of Kassa, particularly where the distance between these sources of pollution and the water points is less than 15 metres.

Table 2: Distance between water sources and vegetable gardens (in metres)

Distance between the tip and the vegetable garden and the well (m)	Number of wells	Percentage (%)
0 à 15	12	75%
15 à 30	1	6,25%
30 à 45	1	6,25%
45 à 60	1	6,25%
> 60	1	6,25%
Total	**16**	**100%**

Most of these rubbish dumps and vegetable gardens are characterised by household organic waste, organic fertilisers and the use of pesticides, all of which contribute to the contamination of groundwater. In particular, leachate from organic waste and chemicals used in vegetable gardens seeps into the soil, thereby increasing the risk of groundwater pollution, especially during the rainy season.

The rubbish dumps and vegetable gardens observed are located at Fotoba 1, Fotoba 2, Fotoba 3, Rogbanè 1, Rogbanè 2, Rogbanè 3, Tamara 1, Room 2, Sorro, Kassa 1, Kassa 2 and Kassa 3 (Table 5).

4.1.3 Proximity to the sea

All sixteen (16) water abstraction points identified in the various areas of the municipality are situated less than 200 metres from the coast (see Table 3). This close proximity to the coastline constitutes a major risk factor for groundwater salinisation due to seawater intrusion, particularly in shallow coastal aquifers.

Table 3: Distance from the coast to the sampling points in the sectors within the municipality of Kassa.

Distance from the coast to the well (m)	Number of wells	Percentage (%)
0 à 50	6	37.50
50 à 100	5	31.25
100 à 150	2	12.50
150 à 200	3	18.75
0 à 200	**16**	**100**

The results indicate that 6 wells (37.5 per cent) are situated less than 50 metres from the shoreline, 5 wells (31.25 per cent) between 50 and 100 metres, 2 wells (12.5 per cent) between 100 and 150 metres, and 3 wells (18.75 per cent) between 150 and 200 metres. All the wells are situated within a 200-metre coastal strip.

4.2 Variation in quality parameters

The results obtained following the analysis of water samples collected during the two seasons are presented and explained in this section for all the physico-chemical and bacteriological parameters studied.

4.2.1 Seasonal variations in physico-chemical parameters

This sub-section examines the seasonal variation in the main physico-chemical parameters of these waters.

4.2.1.1 Water temperature

Temperature is a fundamental physico-chemical parameter that influences many of water's physico-chemical and biological properties, including its density, viscosity, the solubility of gases, the dissociation of salts, and the growth and proliferation of microorganisms [22]. It is an indirect indicator of water's vulnerability to biological contamination. Generally speaking, higher temperatures promote the growth of pathogens and accelerate biochemical reactions.

The measurements taken as part of this study show that well water temperatures are generally higher during the dry season than during the rainy season.

More specifically, only the Room 2 and Sorro wells, with a temperature of 25 °C, and the Rogbanè 1 well, with a temperature of 18.2 °C during the rainy season, comply with the WHO standard for drinking water (T ≤ 25 °C). By contrast, the majority of the other wells have temperatures ranging from 26.3 °C to 34.6 °C, exceeding this reference value, as shown in Figure 2.

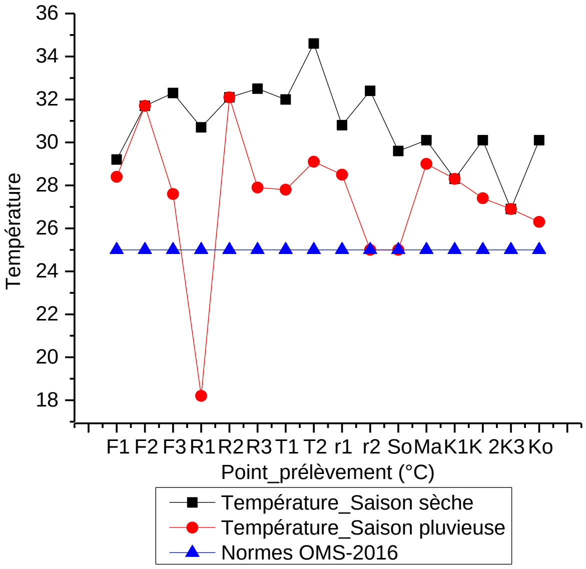

Figure 2: Temperature variation in well water, compared to the WHO standard.

Based on the water quality assessment criteria established by [23] in accordance with WHO standards:

- Excellent water quality (20–22 °C): no samples in our study.
- Water of fair quality (22–25 °C): Room 2 and Sorro during the rainy season.
- Poor-quality water (25–30 °C): Fotoba 1, Kassa 1, Kassa 3 (both seasons), Fotoba 2 and 3, Rogbanè 2 and 3, Tamara 1 and 2, Room 1, Mangué, Kassa 2, Koromandja (rainy season), Sorro and Kassa 1 (dry season).
- Water of substandard quality (30–35 °C): 12 out of 32 samples exceed the recommended thresholds.

4.2.1.2 pH

The pH of water is a key factor affecting its potability. A pH that is too low (acidic) or too high (alkaline) can not only alter the taste of the water, but also affect consumers' digestive health. According to WHO recommendations, the acceptable range for water intended for human consumption is between 6.5 and 8.5 [22].

Analysis of the data from samples taken in April 2024 (dry season) and August 2024 (rainy season), as shown in Figure 3, reveals that only a few wells have pH values that comply with WHO standards. These include:

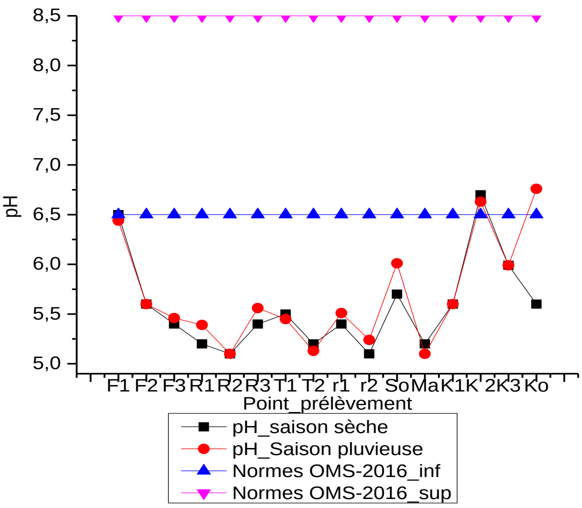

Figure 3. pH variation in well water, compared to the WHO standard.

- Fotoba 1, with a pH of 6.5 in both seasons;
- Kassa 2, with a pH of 6.7 (dry season) and 6.63 (rainy season);
- Koromandja, with a pH of 6.76 in the rainy season.

By contrast, 14 of the 16 wells analysed (87.5 per cent) had pH values below 6.5 across both seasons, including the Koromandja well during the dry season.

4.2.1.3 Electrical conductivity (EC)

Electrical conductivity (EC) is a key indicator of the concentration of dissolved salts in water, and thus reflects its mineralisation. A high EC may indicate the presence of potentially toxic ions (nitrates, chlorides, sulphates, etc.) and pose a health risk: gastrointestinal disorders, electrolyte imbalances or even dehydration, particularly in vulnerable individuals [24].

The results of the analyses, indicate that, of the 32 samples taken during the dry and wet seasons of 2024, 30 have values below the WHO standard of 500 µS/cm. These low conductivity levels indicate reduced mineralisation of the water, probably linked to the geological nature of the underlying bedrock and a low anthropogenic input of dissolved elements.

The Room 1 well, for example, has an electrical conductivity (EC) that complies with the standard during the dry season. During the rainy season, the Kassa 1 well records the highest value amongst the compliant samples, at 360 µS/cm.

4.2.1.4 Turbidity

Turbidity is a measure of water clarity, determined by the concentration of suspended particles, sediments, algae, and organic and inorganic matter. It is expressed in nephelometric units (NTU) and serves as an indirect indicator of the microbiological quality of water [13].

The results of the analyses, reveal significantly higher turbidity during the dry season, with 10 out of 16 wells exceeding the WHO guideline value of 5 NTU for drinking water. The wells concerned are: Fotoba 3 (7.37 NTU), Rogbanè 2 (59.3 NTU), Rogbanè 3 (17.6 NTU), Tamara 1 (13.7 NTU), Tamara 2 (31.7 NTU), Sorro (8.4 NTU), Mangué (16.2 NTU), Kassa 1 (20 NTU), Kassa 2 (53.8 NTU) and Kassa 3 (41.1 NTU).

By contrast, during the rainy season, only three wells – Fotoba 3 (7.37 NTU), Rogbanè 2 (59.3 NTU) and Kassa 2 (8.74 NTU) – exceed this limit.

4.2.1.5 Dissolved oxygen (DO)

Dissolved oxygen (DO) is a key parameter in assessing water quality, both for aquatic life and for human use. In particular, it enables the diagnosis of hypoxia (DO < 5 mg/l) or anoxia (DO ≈ 0 mg/l), which can have serious ecological consequences [25].

As part of this study, analyses carried out on 32 samples revealed DO values ranging from 4.32 to 6.78 mg/l during the dry season and from 4.23 to 6.47 mg/l during the rainy season, as shown in Figure 4. These concentrations remain below the WHO guideline value, which recommends a DO level of > 7 mg/l to ensure optimal drinking water quality [13].

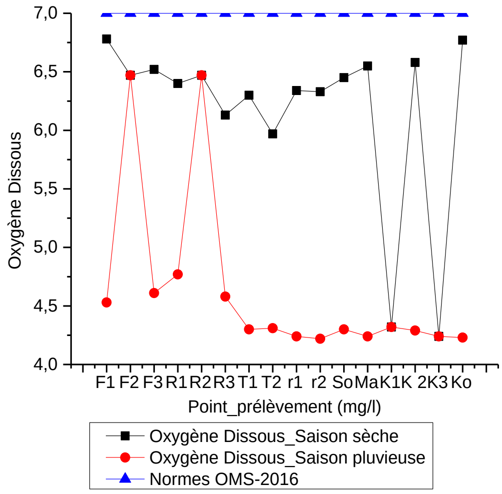

Figure 4. Variation in dissolved oxygen concentration, compared to the WHO standard.

4.2.1.6 Salinity

Salinity refers to the total concentration of dissolved salts in water, comprising mainly sodium (Na^+) and chloride (Cl^-) ions, as well as other ions such as magnesium, calcium, potassium and sulphates. According to WHO standards, drinking water should have a salinity of less than 200 mg/l [26].

The results of the analysis of the 32 groundwater samples collected in the municipality of Kassa show salinity concentrations ranging from 16.6 mg/l to 1,859 mg/l during the dry season, and from 16.6 mg/l to 862 mg/l during the rainy season. The highest concentrations were recorded at the Room 1 and 2, Sorro, Kassa 1 and 3 sites in both seasons, as well as at Kassa 2 and Koromandja during the wet season.

A comparative analysis of the seasons reveals that, at 14 of the 16 sampling points, salt concentrations are higher during the wet season than during the dry season, with the notable exception of Room 2 and Sorro, which show the opposite pattern.

4.2.1.7 Nitrates

Nitrates occur naturally in low concentrations in the soil. However, their contamination of groundwater is often the result of human activity, in particular the leaching of chemical fertilisers and the spreading of manure near wells and septic tanks [27]; [28]. According to the WHO, a nitrate concentration exceeding 10 mg/l poses a risk to public health, particularly for infants and pregnant women (methaemoglobinaemia, or 'blue baby syndrome').

The results of the analyses carried out on the 32 groundwater samples, indicate that all measured concentrations complied with WHO standards (50 mg/l) during the study period. During the dry season, concentrations range from 10.1 mg/l to 36 mg/l, whilst during the rainy season they range from 9 mg/l to 41.6 mg/l.

However, previous research by [29]; [30]; [31] reported concentrations of 40 mg/l in peri-urban areas, 45 mg/l in urban areas and 20 mg/l in rural areas. By comparison, in the Zinder region of Niger, according to [32], the proportion of nitrates amongst the major anions is 19.4 % during the dry season and 17 % during the rainy season.

As regards our study, we observed an increase in nitrate levels in certain wells, notably those in Room 1 and Room 2 (19.2–25 mg/l), as well as in Sorro (36–41.6 mg/l for both seasons).

Like nitrates, nitrites originate mainly from agricultural fertilisers, manure, sewage, and the decomposition of plant and animal matter. These substances are carried into surface waters and groundwater through rainwater infiltration [28].

As part of this study, the results of the well analyses (see Figure 10) show a moderate increase in nitrite levels at certain sites. The wells at Sorro (0.05 and 0.2 mg/l), Mangué (0.03 and 0.09 mg/l), Kassa 1 (0.03 and 0.03 mg/l), Kassa 2 (0.02 and 0.09 mg/l) and Kassa 3 (0.07 and 0.07 mg/l) have concentrations close to the maximum value of the WHO standard, set at 0.2 mg/l. By contrast, in the wells at Fotoba 1, 2 and 3, Rogbanè 1, 2 and 3, Tamara 1 and 2, and Koromandja, nitrite concentrations are extremely low.

4.2.1.8 Total iron

Iron is a naturally occurring element commonly found in soil and rocks. In groundwater, it occurs in various forms, mainly as ferrous iron (Fe^{2+}) and ferric iron (Fe^{3+}). According to the WHO, the maximum recommended concentration of iron in drinking water is 0.3 mg/l. Although iron is an essential nutrient for the human body in small quantities, excessive exposure can lead to gastrointestinal disorders, promote bacterial growth in water supply systems, and cause aesthetic problems (stains, rusty colour).

In our study, only the Room 2 well (during the dry season) has a total iron concentration exceeding the WHO standard (0.3 mg/l).

By contrast, 31 out of 32 water samples analysed in this study comply with WHO standards, with iron concentrations ranging from 0.1 mg/l to 0.3 mg/l during both seasons.

4.2.1.9 Sulphate

In this study, only the Room 2 well showed relatively high sulphate concentrations, with values reaching 39 mg/l and 45 mg/l for the two seasons. However, these concentrations remain well below the WHO standard (200 mg/l). For the other wells (15 in total), sulphate concentrations varied between 0 mg/l and 18 mg/l during the two seasons. The average sulphate concentrations were 5 mg/l in the dry season and 7.7 mg/l in the wet season respectively.

4.2.1.10 Phosphate

Phosphate (PO_4^{3-}) is a polyatomic ion that is essential for various biological processes, playing a key role in photosynthesis, cellular respiration and DNA synthesis. However, when present in high concentrations in groundwater, phosphate can be an indicator of pollution or of the risk of eutrophication in aquatic ecosystems [33].

As the results showed, we're seeing a big increase in phosphate levels in the following wells: Fotoba 1, Rogbanè 3, Tamara 1 and 2, and Room 1 and 2. The measured values range from 21.6 mg/l to 56 mg/l during the dry season, and from 18.1 mg/l to 60 mg/l during the rainy season, indicating significant phosphate pollution in these wells.

A moderate increase in phosphate concentrations was also observed in the Rogbanè 2 and Kassa 1 wells. By contrast, the Fotoba 2 and 3, Rogbanè 1, Mangué, Kassa 2 and 3, and Koromandja wells all comply with the WHO standards (5 mg/l) for phosphate.

In summary, the results show significant variations in water temperature, pH, turbidity, salinity, dissolved oxygen content, electrical conductivity, total iron, nitrates, nitrites, sulphate and phosphate between the two seasons analysed in 2024.

4.3 Variation in bacteriological parameters (dry and wet seasons)

This sub-section examines the seasonal variation in total coliforms, faecal coliforms and faecal streptococci in well water.

4.3.1 Total coliforms

Total coliforms are enterobacteria that include bacterial species living mainly in the intestines of homeothermic animals, but also in the environment (soil, plants, water). These bacteria are used as indicators of the microbial quality of water [28].

In our study, only the Fotoba 1 (0 mg/l) and Kassa 3 (0 mg/l) wells comply with WHO standards (< 10 CFU/100 ml) throughout all seasons. Other wells, such as Tamara 2 (0 mg/l in the dry season), Fotoba 3 (1 mg/l), Rogbanè 1 (0 mg/l), Rogbanè 3 (2 mg/l), Tamara 1 (3 mg/l), Room 2 (0 mg/l), Mangué (2 mg/l), Kassa 2 (4 mg/l), and Koromandja (0 mg/l) also meet WHO standards during the wet season.

However, several wells exceed WHO standards. Total coliform concentrations in the Fotoba 2 (160 mg/l) and Rogbanè 2 (103 mg/l) wells are high in each season, respectively. Similarly, the Room 1 (25 mg/l in the dry season and 23 mg/l in the wet season) and Sorro (39 mg/l in the dry season and 16 mg/l in the wet season) wells also have concentrations above the standard. Furthermore, samples taken during the dry season from the Fotoba 3, Rogbanè 1 and 3, Tamara 1, Room 2, Mangué, Kassa 1, Kassa 2 and Koromandja wells, with respective values of 102, 100, 46, 200, 210, 12, 20, 2,000 and 64 mg/l, do not comply with WHO standards.

4.3.2 Faecal coliforms

Faecal coliforms (or thermotolerant coliforms) are a subgroup of total coliforms capable of fermenting lactose at a temperature of 44.5 °C. Their presence is directly linked to faecal contamination and serves as an indicator of potential health risks [28].

According to the analysis results for the 32 samples collected during the two seasons, only 10 samples met the WHO standards in all seasons; 1 sample met the standards during the dry season and 3 samples met the standards during the rainy season. The Fotoba 2 and Rogbanè 2 wells have values of 13 CFU/100 ml and 11 CFU/100 ml respectively in each season. Other wells, such as Rogbanè 1 (1), Rogbanè 3 (47) and Tamara 1 (70 CFU/100 ml) during the dry season, and Tamara 2 (5 CFU/100 ml) during the wet season, exceed the WHO limit of 0 CFU/100 ml.

4.3.3 Faecal streptococci

According to the results shown in Figure 5, three main trends were observed regarding the presence of faecal streptococci:

- Compliance with WHO standards throughout the year at the Fotoba 2 and Rogbanè 2 wells.
- Compliance with standards during the dry season for the Fotoba 1, Fotoba 3, Rogbanè 1, Rogbanè 3, Tamara 1, Tamara 2, Room 1, Room 2, Sorro, Mangué, Kassa 1, Kassa 2, Kassa 3 and Koromandja wells.
- A significant increase in the concentration of faecal streptococci in the same wells during the rainy season, with results exceeding WHO standards (0 CFU/100 ml).

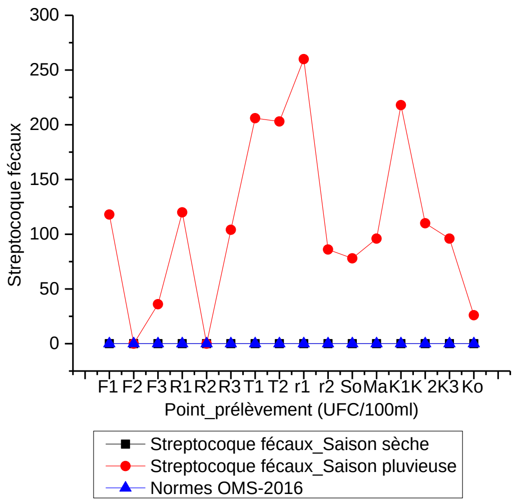

Figure 5: Variation in fecal streptococcal concentration, compared to the WHO standard

4.4 Contamination levels in water samples

Given that the total number of water samples per season is 16, the contamination rates of the water samples analysed are summarised in Table 7.

4.4.1 Summary of results

An analysis of the figures and statistics enables us to draw up a summary profile on which the discussion will be based:

- The main sources of pollution identified around the wells: latrines (43.75 % within <15 m), laundry areas, vegetable gardens (75 %<15 m) and rubbish dumps.
- All 16 wells are located less than 200 m from the shoreline, with 37.5 % less than 50 m away, which is a risk factor for salinisation.
- Physico-chemical parameters: 84.38 % with a pH < 6.5; 90.63 % with abnormal temperatures; 40.63 % with turbidity > 5 NTU; 3.13 % with EC > 500 µS/cm; 93.75 % failing the STD test; 50 % polluted by phosphates; 100 % with DO < 7 mg/l; 6.25 % with total iron > 0.3 mg/l.

- Bacteriology: 56.25 % for total coliforms; 28.13 % for faecal coliforms; 43.75 % for faecal streptococci.

These figures and statistics form the factual basis on which the discussion will draw to support comparisons with the literature and the discussion of the mechanisms at play.

5 DISCUSSION

5.1 Physico-chemical parameters

This seasonal difference (dry season > wet season) can be explained by intense sunshine and the rise in soil temperature during the dry season, in contrast to the dilution caused by rainwater infiltration during the wet season. These results are consistent with data from the literature : For example, [34] measured temperatures of around 27 °C in the shelf waters off the Soubré department (Ivory Coast), whilst Souley et al. (2018) report values ranging from 27.6 °C to 32.2 °C during the dry season and from 28.4 °C to 32 °C during the rainy season in the Zinder region (Niger). These figures confirm that the abnormally high temperatures measured at Kassa are consistent with the regional trend for shallow groundwater in tropical areas.

According to the OMS (2016), a temperature of 22 °C is already considered relatively high for groundwater, and temperatures above 25 °C significantly increase the risk of microbial proliferation, particularly of pathogenic bacteria, viruses and protozoa, which can cause gastrointestinal infections. Similarly, high temperatures promote evaporation, thereby concentrating certain chemical contaminants such as nitrates, pesticides and heavy metals [35]. These factors justify the recommendation for continuous temperature monitoring in order to prevent both microbiological and chemical risks.

These slightly acidic to neutral values are comparable to those reported in other bedrock areas, such as south-western Côte d'Ivoire, where [34] observed an average pH of around 6.8. Similarly, in the Zinder region (Niger), [32] recorded pH values ranging from 6.99 (dry season) to 6.87 (rainy season), confirming that groundwater acidity is a regional characteristic.

This widespread acidity may result from the water passing through geological layers rich in siliceous rocks or decomposing organic matter, which release organic acids during their microbial mineralisation [36].

A pH that is too acidic can:

- Cause corrosion of well and pipework materials (lead, copper);
- Promote the release of heavy metals into the water, which may cause neurological and renal disorders in exposed populations [37] ;
- Alter the taste of the water and cause gastrointestinal irritation in susceptible individuals [38].

It is therefore essential to monitor and, where necessary, adjust the pH of these waters to ensure their sanitary quality and protect public health. The strong negative correlation observed between pH and faecal coliforms ($r = -0.968$) supports the hypothesis that an acidic environment promotes bacterial survival, in line with the findings of [39].; [40].

Similar studies carried out in the Zinder region (Niger) by [32] reported electrical conductivity (EC) values ranging from 116.3 to 2,650 µS/cm during the rainy season, and from 113.5 to 2,490 µS/cm during the dry season, demonstrating variability linked to the geological environment and local practices. Similarly, [41] pointed out that even moderate conductivity (for example, 410 µS/cm) may require regular monitoring of chemical parameters to ensure the potability of groundwater, in the context of climate change.

The high reading recorded at Room 2 well during the dry season (1,638 µS/cm) may be explained by contamination from pollutants, as has also been noted by [29] ; [42] ; [31] ; [43] in other geographical contexts. This hypothesis is consistent with the high concentrations of total iron, sulphate and salinity measured at the same Room 2 well.

In Mexico, studies carried out in 2021 documented electrical resistivity (CE) values exceeding 600 µS/cm in certain aquifers, leading to difficulties in supplying drinking water in rural areas. Furthermore, [44] demonstrated that agricultural irrigation using water with a conductivity (EC) exceeding 650 µS/cm could adversely affect crop yields.

The high mineralisation observed in certain samples could therefore be due to:

- The nature of the geological formations traversed (rich in soluble minerals),
- And human activities, in particular domestic or agricultural discharges, as highlighted by [45].

Finally, high conductivity is frequently associated with the presence of inorganic (nitrates, heavy metals) and organic contaminants, which may have adverse effects on the kidneys and liver, particularly in the event of prolonged exposure.

High turbidity is often linked to microbiological contamination: suspended particles provide a haven for bacteria, viruses and protozoa, thereby reducing the effectiveness of disinfection processes. Consequently, turbid water may not be safe to drink without prior treatment, in particular disinfection by chlorination, the effectiveness of which is reduced when turbidity is high [28].

This phenomenon, observed during the dry season, can be explained by several factors:

- The drop in water levels in wells leads to a higher concentration of suspended solids and facilitates the rise of solid particles, including sediment, organic debris and, in some cases, faecal matter.
- Intensive use of wells during this period increases mechanical disturbance in the water, thereby increasing turbidity.
- The resuspension of mineral matter from the subsoil, caused by repeated pumping, may contribute to this increase [46].

Conversely, during the rainy season, groundwater recharge leads to a dilution of suspended particles and a relative decrease in turbidity in the majority of the wells sampled, despite a possible increase in turbidity during the very first rains (initial flushing effect).

It is therefore crucial to monitor this parameter systematically, as high turbidity compromises not only the visual quality of the water but also its safety, particularly in rural areas where water treatment is often rudimentary.

These results indicate moderate oxygenation of the groundwater in the municipality of Kassa, which is likely linked to several factors:

- The breakdown of organic matter by aerobic microorganisms, a process which consumes some of the available oxygen;
- Limited water renewal in certain shallow wells;
- The possible presence of eutrophying substances (phosphates, nitrates) that promote algal blooms, the subsequent decomposition of which further reduces the dissolved oxygen (DO).

A study carried out in 2020 on Lake Erie, on the border between Canada and the United States, revealed concentrations of dissolved oxygen (DO) below 5 mg/l, caused by agricultural run-off and harmful algal blooms, which have had a profound impact on aquatic wildlife [47].

A similar issue can be observed in the shallow wells at Kassa, where the combination of organic matter and phosphates creates conditions conducive to high biochemical oxygen demand.

Conversely, more encouraging results have been achieved in Europe, where ecological restoration efforts (reducing organic discharges, reforesting riverbanks) have led to DO levels exceeding 8 mg/l, with a positive impact on aquatic biodiversity [48].

Furthermore, a 2021 Californian study reported that certain groundwater bodies contained OD levels of between 6 and 8 mg/l, which were deemed suitable for drinking water, whilst emphasising the need for regular monitoring to prevent any risk of contamination [49].

According to the [50] dissolved oxygen (DO) is not only a key indicator of the functioning of aquatic ecosystems, but also a marker of drinking water quality. The negative correlation observed between DO and pH ($r = -0.890$) in our study is consistent with the findings of [51] on O_2/organic matter dynamics in stagnant waters.

In conclusion, the readings taken at Kassa call for greater vigilance regarding the protection of aquifers and the management of organic inputs, in order to prevent a continued deterioration in groundwater quality.

A similar situation was observed in Kaolack (Senegal), where salinity levels in drinking water reached as high as 124 g/l [52]. This study highlights that high levels of dissolved salts can not only impair the organoleptic quality of water, but also seriously harm aquatic ecosystems and public health.

This seasonal trend was also documented by [53] in their study of the waters of the southern Saloum Basin (Senegal), highlighting the impact of soil leaching, groundwater recharge and the remobilisation of salts during heavy rainfall.

As regards Room 2 (1,116 mg/l in the dry season compared with 860 mg/l in the wet season) and Sorro (1,859 mg/l compared with 372 mg/l), the situation appears to be influenced by their topographical location and their relative proximity to the sea. During the dry season, reduced water recharge combined with saline intrusion facilitated by high tides could explain the higher salinity. This phenomenon has also been observed in the Saloum region, as described by [54], where increased marine intrusion during the dry season has been identified as a major factor in the salinisation of wells.

In short, the high salinity levels recorded at several sites, notably Sorro and Room 2, indicate that groundwater resources are vulnerable to seawater intrusion or contamination by natural salts. This situation calls for rigorous monitoring measures and strategies to protect aquifers in order to ensure sustainable access to good-quality water.

However, studies have shown that urban areas have significantly higher nitrate concentrations (45 mg/l) compared with rural areas (20 mg/l) [29]; [30]. By comparison, in the Zinder region of Niger, [32] found that the proportion of nitrates among the major anions was 19.4 % during the dry season and 17 % during the rainy season.

Conversely, in the study by [55] in Thiaroye-Pikine (Senegal), nitrate concentrations in groundwater far exceeded the 50 mg/l limit set by the WHO. Similarly, [56] observed that in north-eastern Algeria, intensive agricultural activity was leading to nitrate concentrations of 80 to 120 mg/l.

These figures are likely linked to the impact of domestic pollution and agricultural activities in the region, as demonstrated by the research carried out by [57]; [58] in Yékoua (Côte d'Ivoire).

Similar findings were observed in Well No. 1 at Abattoir and Well No. 3 at Poudrière in Mamou [46]. A study published in 2022 analysed the health impact of nitrates and nitrites in several European countries. The researchers found a correlation between high levels of these compounds and an increase in hospital admissions for respiratory problems among young children.

Furthermore, a study carried out in 2021 assessed nitrite contamination in groundwater near areas of intensive agriculture in Europe. The results revealed that, in certain regions where nitrogen fertilisers were used extensively, nitrite levels often exceeded 0.4 mg/l. A report published by an environmental agency in 2023 recommended regular monitoring and strict management of water resources to prevent any future contamination.

It is therefore essential to emphasise that drinking water with nitrate concentrations exceeding 50 mg/l poses a health risk, particularly in the case of prolonged consumption, especially for infants and pregnant women (methaemoglobinaemia).

The increase in the iron content in Well Room 2 can be explained by the reduction in the volume of water in that well, which leads to an increase in the iron content due to the weathering of minerals and rocks. These minerals include amphiboles, ferromagnesian micas, iron sulphides, magnetites, oxides, carbonates and ferruginous clay minerals. This diversity of mineral sources explains the moderate correlation observed between iron and EC (r = 0.553) and between iron and sulphates (r = 0.638), confirming a common geochemical origin (mineral dissolution).

Similar results were observed in the Zinder Basement region of Niger, where total iron (Fe^{2+}, Fe^{3+}) concentrations ranged between 0.37 mg/l and 0.38 mg/l at the FM2 and PC1 sites during the rainy season. However, during the dry season, the concentration reached 1.81 mg/l at the PC1 site [32].

A study published in the [50] indicated that moderate concentrations of sulphate, such as those measured in this study (up to 45 mg/l), do not generally pose an immediate risk to health, although they do require ongoing monitoring. The strong correlation between SO_4^{2-} and CE (r = 0.934) and between SO_4^{2-} and DTS (r = 0.928), as observed in our Spearman's correlation matrix, highlights the major contribution of sulphates to mineralisation. According to [59], this strong binding is of either mineral origin (oxidation of pyrite, dissolution of evaporites) or anthropogenic origin (sulphate fertilisers).

However, a study carried out in 2021 revealed that some aquifers in California had high sulphate levels, attributable to intensive agricultural activities. Research carried out in Canada in 2022 showed that some rural areas were experiencing a significant increase in sulphate levels due to the increased use of sulphur-containing fertilisers.

According to the [60], high concentrations of sulphate in groundwater must be monitored regularly in order to prevent any potential impact on public health, in particular laxative effects in some people, which may lead to dehydration and other gastrointestinal problems.

A study conducted by [61] revealed that elevated phosphate levels in groundwater were associated with an increase in harmful algae blooms in adjacent rivers, suggesting eutrophication. Similar results were observed in the study by [46], in which 27 out of 45 wells were also contaminated with phosphates.

[62] also reported that excessive levels of phosphate in the human body can lead to health problems such as kidney disorders or osteoporosis.

A study conducted by [63] in Switzerland showed that even relatively low concentrations of phosphates can trigger algal blooms in sensitive aquatic ecosystems, highlighting the need for rigorous management of phosphate concentrations in water resources.

5.2 Bacteriological parameters

The rise in total coliform concentrations in these wells can be attributed to environmental degradation and increased use of these wells by the local population. A similar situation was observed on the Thiaroye-Pikine Peninsula (Senegal), where bacterial contamination of groundwater posed a threat to public health [55].

A similar issue was identified in Lomé (Togo) in the study by [64], where the results of analyses carried out on well water also revealed contamination by total coliforms. Other studies conducted by [62] also observed high concentrations of these bacteria in well water in their study area.

In short, the presence of total coliforms in water is a direct indicator of deteriorating water quality and highlights the need for effective water resource management to ensure water safety and prevent health risks.

Research by [65] revealed that poorly managed sanitation systems contribute significantly to the deterioration of water quality, leading to high levels of coliform bacteria. The marked increase in faecal coliforms and E. coli could be attributed to faecal pollution of animal or human origin. This pollution results, amongst other things, from the use of septic tanks, the rearing of small ruminants, or the use of their manure as fertiliser in vegetable gardens surrounding wells[62].

This contamination during the rainy season is attributed to poor control of surface water runoff and irresponsible household practices, such as a lack of appropriate sanitation measures.

The studies by [62] and [66] have highlighted an alarming prevalence of pathogenic bacteria in groundwater, emphasising the importance of regular monitoring to ensure the safety of drinking water. Furthermore, research by [64] in Lomé (Togo) revealed similar levels of faecal streptococci contamination in well water. A study conducted by [67] in Ouahigouya (Burkina Faso) found that all the well waters examined were heavily contaminated with pathogenic microorganisms.

Consequently, this well water is not recommended for human consumption as it stands. However, it can be made safe to drink under certain conditions, such as boiling followed by cooling, in order to kill any pathogens present. The correlation observed between SF and PO_4^{3-} (r = 0.506) confirms the hypothesis of contamination of domestic origin: phosphate-based detergents and animal/domestic waste are both found in the leachate.

6 CONCLUSION

This study, carried out in April and August 2024, assessed the physico-chemical and bacteriological quality of drinking water in the municipality of Kassa. The results show that few parameters meet WHO standards, with significant levels of contamination during both seasons: non-compliant pH (84.38 %), abnormal temperature (90.63 %), excessive turbidity (40.63 %), TDS outside the standard (93.75 %), insufficient dissolved oxygen content (100 %), as well as significant bacteriological contamination (total coliforms: 56.25 %; faecal coliforms: 28.13 %; faecal streptococci: 43.75 %).

This pollution is due to the dilapidated state of water sources, their proximity to latrines, vegetable gardens and rubbish dumps, the lack of a drainage system, the exposure of wells to surface runoff, the poor quality of cesspits, and certain inappropriate practices by users when drawing water.

In light of these findings, it is recommended that the administrative and health authorities:
- implement integrated water resource management (piezometric monitoring, bacteriological surveillance, control of pollution sources);
- promote water treatment prior to consumption (boiling, chlorination, filtration);
- draw up a local sanitation plan with the support of development partners;
- raise community awareness of good hygiene practices;

- carry out more detailed analyses (heavy metals, pesticides, isotopic dating) to better identify the vulnerability of water sources.

Ultimately, the municipality of Kassa requires special attention in order to bring about a lasting improvement in the living conditions of its population.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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The authors declare no conflicts of interest regarding this manuscript.

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