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Assessment of Nitrates and Nitrites in Borehole Water from the Southern and the Northern Region of Côte d'Ivoire (West Africa)

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Abstract

This study aimed to evaluate the quality of water from village boreholes by measuring physicochemical parameters such as nitrates, nitrites, and total organic carbon (TOC). Forty-five (45) village pumps from the Southern (Basse Côte) and the Northern (Korhogo) region of Côte d'Ivoire (west Africa) were sampled. Physicochemical parameters such as temperature, pH, conductivity at 25˚C, and turbidity were determined *in situ*, while nitrite and nitrate were analyzed according to ISO 10304-1 (2007) standard and total organic carbon (TOC) by NF EN 1484 (1997) standard. The results showed that the borehole waters of the Basse Côte and Korhogo analyzed are acidic, with an average temperature of 27.51˚C ± 0.16˚C and 29.95˚C ± 0.51˚C respectively for the Basse Côte and Korhogo regions. The borehole waters of the Basse Côtedo not contain nitrites, while those of Korhogo have average nitrite contents of 0.32 mg/l. The average nitrate rate in the waters of the Basse Côte and Korhogo are 12.08 ± 2.11 mg/l and 11.03 ± 3.18 mg/l respectively. The average TOC concentration of the waters of the Basse Côte is 1.28 ± 0.32 mg/l and that of Korhogo is 0.56 ± 0.09 mg/L. The study showed that the borehole waters of the Basse Côte and Korhogo have average temperatures between 27.4˚C and 29.95˚C with a slightly acidic pH value and acceptable salinity. The TOC concentrations obtained at the different sampling points were all below the French standard (2 mg/L) except for certains pumps of the Basse Côte. The water samples from the Basse Côte were devoid of nitrite. On the other hand, those from Korhogo revealed the presence of nitrite. Also, the borehole waters of the regions of the Basse Côte and Korhogo contain relatively high nitrate contents, presumably due to anthropometric activity. Overall, our study on the quality of drinking water showed that the waters analyzed are in compliance with international standards and safe for consumption.

Keywords

Drinking Water, pH, Turbidity, TOC, Nitrates, Nitrites, Health Effect

1. Introduction

Water is essential for all forms of life. It is also a crucial element for promoting individual health and the socio-economic development of human communities. Unfortunately, many parts of the world lack access to clean drinking water [1] [2]. According to the United Nations, nearly 884 million people worldwide do not have access to quality drinking water, and among them, two million people mostly young children die each year due to diseases caused by unsafe water consumption (UN, 2022) [3] [4]. In Africa, over 400 million people, almost half of the population, lack proper access to a safe and sufficient water resource [5] [6]. In Côte d'Ivoire, nearly half of the total population lacks access to clean water.

To address the water scarcity, especially in rural areas, the government has established several water wells equipped with hand-operated pumps. Groundwater plays a significant role, particularly in drinking water, and constitutes the largest reserves of freshwater distributed globally [7]. It serves as the sole source of water for the majority of populations [8] [9]. Understanding its chemical composition is essential for ensuring water quality and safety for human consumption. Groundwater from wells can be contaminated by nitrates from soil mineralization, atmospheric nitrogen deposition, industrial residues, or intensive agriculture. Excessive levels of nitrate and nitrite compounds or living organisms in groundwater pose serious health risks [10] [11]. Indeed, once nitrate (NO_3) is ingested through water, it metabolizes into bioactive nitrite (NO_2) and enters the bloodstream [12]. It can react with amines and amides in the body through nitrosation, forming N-nitroso compounds (NOCs) that contribute to the development of certain cancers in humans. N-nitroso compounds (NOCs) are carcinogenic for humans and are classified as Group 2A by the International Agency for Research on Cancer (IARC) [13]. Various studies strongly suggest that elevated levels of nitrates, nitrites, and NOCs in water and food are linked to the development of colorectal cancer [14]. Cases of epithelial ovarian cancer have also been reported in women who drank water from public sources with high nitrate and nitrite levels in the Iowa region. Similarly, exposure to high nitrate levels in municipal water and bottled drinking water has been associated with an increased risk of prostate cancer [15].

Therefore, the effective means of controlling nitrate and nitrite concentrations in drinking water remains to prevent contamination (water pollution) [14]. The

WHO has even published guidelines on safe concentrations of nitrate and nitrite compounds in water for human use [16] [17]. However, in some developing African countries, nitrate and nitrite concentrations in shallow waters and wells are not always adhered to. Hence, this study was undertaken [18]. This study focused on evaluating the quality of groundwater in the Southern and Northern regions, specifically in the Basse Côte regional district and Korhogo. In these areas, the use of fertilizers and pesticides in agricultural activities, as well as other industrial activities, can lead to water contamination. The main objective of our study was to quantify the chemical composition, including nitrate ions (NO_3^-), nitrites (NO_2), and total organic carbon (TOC) in the groundwater from wells in these two regions, which may be affected by pollution.

2. Materials and Methods

2.1. Area Study

The study area covered five (05) regions of Côte d'Ivoire, namely: Poro, Sud-Comoé, Agnéby-Tiassa, Grands-Ponds, and Sud-Comoé, as well as the Autonomous District of Abidjan. According to the classification by the Société de Distribution d'Eauen Côte d'Ivoire (SODECI), the Poro region is part of the Korhogo regional directorate, with a population of 1,040,461 inhabitants distributed among 180,173 households. The other regions belong to the Basse-Côte, with a population of 8,421,868 inhabitants and 1,827,972 households (RGPH, 2021). The Poro region is situated between 5˚ and 9˚28' north latitude, and 5˚43' and 8˚ west longitude, while the Basse Côte lies between 5˚ and 9˚50' north latitude, and 6˚50' and 8˚ west longitude (**Figure 1**).

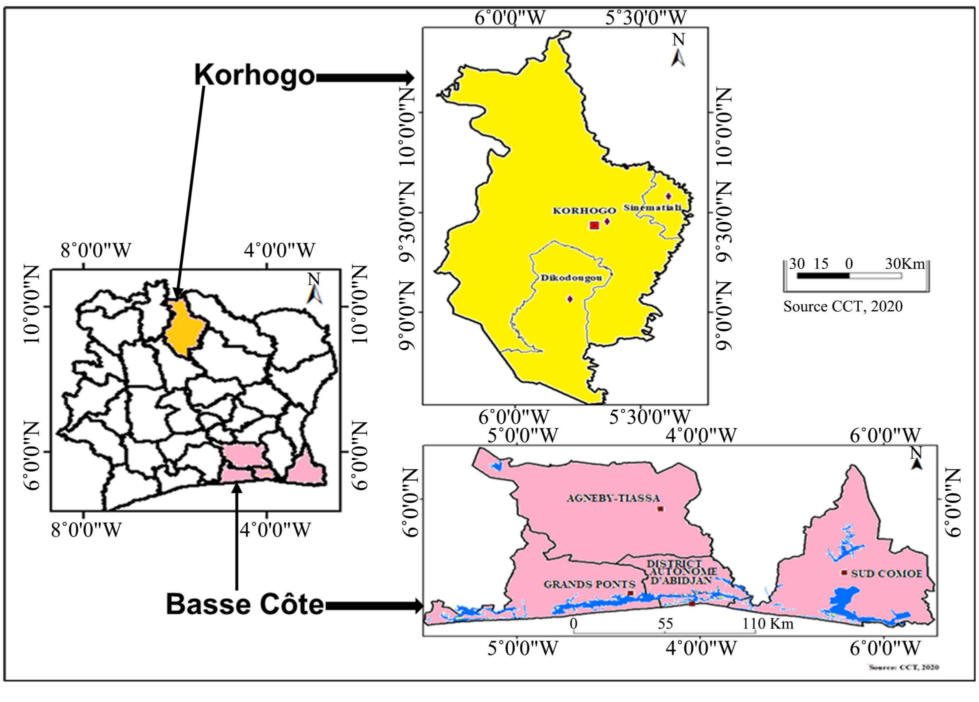

Figure 1. Sampling regions for groundwater samples (Korhogo et Basse Côte).

2.2. Sampling Method

The sampling equipment consists of coolers (26 L - 65 L) for sample preservation and a thermometer (Data logger) to monitor temperature changes during transportation. The study focused on water from 45 boreholes, including 22 at the Basse Côte and 23 at Korhogo (Table 1).

2.3. pH. Temperature, Conductivity and Turbidity

The pH, conductivity, and temperature were measured *in situ* using a portable multimeter of type HANNA, HI 991300, while turbidity was obtained with the help of a turbidimeter of type HACH 2100 QiS. The physical parameters were measured with the HANNA HI 991300 portable multimeter and the HACH 2100 QiS turbidimeter. The HACH 2100 QiS turbidimeter is an instrument that allows the measurement of temperature, pH, and conductivity. It is lightweight, compact, and waterproof, making it ideal for routine field checks. The device is equipped with a screen that simultaneously displays the pH or conductivity (or TDS) and temperature. It is equipped with a solid multiparameter probe and excellent resistance to aggressive environments. Calibration is performed by simply pressing a button, allowing access to pre-recorded pH buffer solution and conductivity values.

The HACH 2100 QiS turbidimeter is a portable device that offers unparalleled accuracy for turbidity measurement. It is equipped with an innovative operating mode, the "Rapidly Settling Turbidity", which allows precise measurements even with samples presenting the highest settling powers. Calibration and verification are simplified, and data transfer is very simple.

2.4. Determination of Nitrites and Nitrates

The quantification of dissolved nitrites and nitrates is carried out according to ISO 10304-1 2007 standard by liquid phase ion chromatography using Metrohm equipment, specifically the 930 Compact IC Flex system, equipped with a conductivity detector and a MetrosepA Supp column (150 mm × 4 mm). The MetrosepA Supp 4/5 Guard/4.0 pre-column is heated to 45˚C, and an automatic sampler, 858 Professional Sample Processor, is equipped with a tangential filtration device for samples using 0.22 µm porous filters. The injection flow rate is set at 0.9 mL/min, and chromatogram acquisition and evaluation are performed

Table 1. Number of pumps by region or district.

SODECI Regional Office	Region/District	Number of pumpsunits
Basse Côte	District Autonome d'Abidjan	4
	Grands-Ponds	1
	Agnéby-Tiassa	1
	Sud-Comoé	16
Korhogo	Poro	23

using MagICNet software. For each compound, calibration is performed using a single standard corresponding to the upper level of calibration range 1 (STD 1), with other levels obtained by diluting calibration range 1 (STD1).

2.5. Determination of Total Organic Carbon

The determination of total organic carbon content in water samples was performed using a multi N/C 3100 carbon analyzer (Analytikjena, Germany), equipped with an AS-Vario sample changer with two probes, an 800˚C combustion furnace, and a non-dispersive infrared absorption detector (NDIR). The system is automatically controlled and evaluated using the multiWin software.

2.6. Detection Limit (DL) and Quantification Limit (QL)

For nitrites, nitrates, and total organic carbon analyzed, the lower values of the calibration ranges were selected as the limit of quantification. Indeed, 0.06 mg/L and 0.6 mg/L represent the values below which the obtained concentrations differ from those expected according to the quantification protocol, respectively for NO_2^- and NO_3^-. Regarding TOC, the value of 0.3 mg/L was chosen as the lower limit of the method's application range. By adhering to these values and to ISO/TS 13530 (2009) standard, the limits of quantification are obtained according to the following relationship (1):

$$\text{LD} = \frac{LQ}{3} \tag{1}$$

Limite de détection (mg/l).
Limite de quantification (mg/l).

2.7. Statistical Analysis

The statistical analysis of the data was carried out using the GraphPad Prism 5.0 software. Quantitative variables are summarized as the mean value and standard deviation in the tables and figures. For statistical analysis. quantitative data were analyzed using the Mann-Whitney U test. according to their distribution evaluated by the Shapiro-Wilk test. All tests were two-tailed and viewed as indicating statistical significance at a p-value of less than 0.05.

3. Results and Discussion

3.1. Results

3.1.1. Physical Parameters Measured *in Situ* in Basse Côte in Korhogo

Table 2 presents the physical parameters, such as temperature, pH, conductivity, and turbidity, measured *in situ* at various sampling points in the Basse Côte and Korhogo regions. Throughout the study, temperatures ranged between 26.30˚C and 29.50˚C, with an average of 27.51˚C ± 0.16˚C and a median temperature of 27.4˚C for the Basse Côte wells. For Korhogo, temperatures varied from 20.60˚C to 34.80˚C, with an average of 29.95˚C ± 0.51˚C and a median temperature of 29.80˚C. However, the average water temperature in Korhogo was significantly

Table 2. Mean of physical parameters measured *in situ* in Basse Côte and Korhogo.

Physical Parameters		Basse Côte (N = 22)	Korhogo (N = 23)	P-value
Temperature (˚C)	Mean	27.51 ± 0.16	29.95 ± 0.51	
	Median	27.40	29.80	<0.0001*
	Min.- Max.	26.30 - 29.50	20.60 - 34.80	
pH	Mean	5.24 ± 0.12	6.33 ± 0.05	
	Median	5.15	6.40	<0.0001*
	Min.- Max.	4.60 - 6.50	5.90 - 6.80	
	WHO standard (2017)	6.5 < pH < 8.5		
Conductivity à 25˚C (µs/cm)	Mean	94.36 ± 16.06	171.8 ± 19.36	
	Median	57.85	163.1	0.0038
	Min.- Max.	23.20 - 272.0	68.40 - 402.0	
Turbidity (NTU)	Mean	3.24 ± 1.48	8.16 ± 3.23	
	Median	0.78	2.82	0.1802
	Min.- Max.	0.41 - 31.20	0.89 - 72.10	

higher ($p < 0.0001$) than that in the Basse-Côte.

The measured pH values ranged from 4.60 to 6.50, with a median of 5.15 and an average of 5.24 ± 0.12 for the Basse Côte pumps. In contrast, the pH values for Korhogo were between 5.90 and 6.80, with a median of 6.40 and an average of 6.33 ± 0.05, showing a highly significant difference ($p < 0.0001$) compared to the Basse-Côte.

Conductivity at 25˚C varied from 23.20 µs/cm to 272.0 µs/cm, with an average of 94.36 ± 16.06 µs/cm and a median of 57.85 µs/cm for the Basse Côte wells. For Korhogo, conductivity values ranged from 68.40 µs/cm to 402.0 µs/cm, with an average at 25˚C of 171.8 ± 19.36 µs/cm and a median of 163.1 µs/cm. The average conductivity of water from Korhogo was significantly higher ($p = 0.0038$) compared to that from the Basse Côte (Table 2).

Turbidity measurements (NTU) showed values ranging from 0.41 NTU to 31.20 NTU, with an average of 3.24 ± 1.48 and a median of 0.78 for the Basse Côte wells. In Korhogo, turbidity values varied from 0.89 NTU to 72.10 NTU, with a median of 2.82 and an average of 8.16 ± 3.23. The average turbidity (NTU) of water from Korhogo was slightly higher than that from the Basse Côte (3.24 ± 1.48 NTU), but the difference was not significant ($p = 0.1802$) (Table 2).

3.1.2. Chemical Parameters Measured *in Situ* in Basse Côte and Korhogo

Table 3 and Table 5 present the concentrations of nitrite, nitrate, and organic carbon measured in the groundwater from wells in the Basse Côte and Korhogo regions. The results show traces of nitrites in the Basse Côte wells. Conversely, in Korhogo, the well waters exhibit nitrite concentrations ranging between 0.07 mg/l and 0.60 mg/l, with an average of 0.33 ± 0.11 and a median value of 0.32 mg/l (Table 3).

Table 3. Nitrate values. nitrites and TOC in water at the level of the Basse Côte SODECI Regional office.

SODECI Regional office	Pumps	Nitrites (mg/l)	Nitrates (mg/l)	COT (mg/l)
	P1	0	29.36	1.34
	P2	0	17.96	4.43
	P3	0	23.28	4.82
	P4	0	9.21	1.01
	P5	0	12.87	0.52
	P6	0	2.20	5.48
	P7	0	1.04	0.96
	P8	0	5.97	0.77
	P9	0	7.07	0.95
	P10	0	12.15	1.53
	P11	<0.06	11.34	0.43
Basse Côte	P12	0	4.35	0.54
	P13	<0.06	<0.6	0.34
	P14	0	8.15	0.49
	P15	0	41.30	0.34
	P16	0	10.15	0.70
	P17	0	5.52	0.43
	P18	0	17.1	0.52
	P19	0	6.25	0.43
	P20	0	6.68	0.821
	P21	0	16.21	0.69
	P22	0	5.44	0.63

Table 4. Mean concentrations of nitrites, nitrates and total organic carbon in Basse Côte and Korhogo.

Chemical Parameters		Basse Côte (N = 22)	Korhogo (N = 23)	P-value
Nitrites (mg/l)	Mean		0.33 ± 0.11	
	Median		0.32	
	Min.- Max.		0.07 - 0.60	
	WHO standard (2017)	3		
Nitrates (mg/l)	Mean	12.08 ± 2.11	11.03 ± 3.18	
	Median	9.21	6.51	0.2177
	Min.- Max.	1.04 - 41.30	0.62 - 65.80	
	WHO standard (2017)	50		
COT (mg/l)	Mean	1.28 ± 0.32	0.56 ± 0.09	
	Median	0.69	0.41	0.0092**
	Min.- Max.	0.34 - 5.48	0.30 - 1.51	
	WHO standard (2017)	2		

*p < 0.05; **p < 0.01; ***p < 0.005; et ****p < 0.001 vs Control.

Only pump P28, P40, and P41 revealed the presence of nitrites, with respective values of 0.35 mg/l, 0.29 mg/l, and 0.60 mg/l (Figure 2(a) and Figure 2(b))). The nitrate levels in the well waters range from 1.04 mg/L to 41.30 mg/L, with an average of 12.08 ± 2.11 mg/L and a median of 9.21 mg/L in the Basse Côte water. For Korhogo, nitrate concentrations vary from 0.62 mg/L to 65.80 mg/L, with an average of 11.03 ± 3.18 mg/L and a median of 6.51 mg/L in the well waters (Table 3). Elevated nitrate levels were observed in the waters from pumps P1 (29.36 mg/l) and P15 (41.30 mg/l) in the Basse Côte region, as well as pumps P24 (65.80 mg/l) and P45 (48.44 mg/l) (Figure 2(a)). The results for total organic carbon (TOC) concentrations are recorded in Table 4 and Figure 3(a) and Figure 3(b).

The TOC concentrations in the Basse Côte well waters vary from 0.34 mg/l to 5.48 mg/l, with an average of 12.08 ± 2.11 mg/l and a median of 9.21 mg/l. For Korhogo, the TOC values range between 0.30 mg/l and 1.51 mg/l, with an average concentration of 0.56 ± 0.09 mg/l and a median of 0.41 mg/l. The highest TOC concentrations were observed in the waters from pumps P2 (4.43 mg/l), P3 (4.82 mg/l), and P16 (5.48 mg/l) in the Basse-Côte, while pump P34 (1.51 mg/l) recorded the highest TOC concentration in Korhogo (Figure 3(b)).

Table 5. Nitrate, nitrite and TOC values in water at SODECI's Korhogo regional office.

SODECI Korhogo regional office	Pumps	Nitrites mg/l	Nitrates (mg/l)	TOC (mg/l)
	P23	0	24.19	0.30
	P24	<0.06	65.80	<0.3
	P25	<0.06	2.65	0.41
	P26	0	1.82	0.52
	P27	0	0.62	<0.3
	P28	0.349	4.82	0.39
	P29	0	0.94	<0.3
	P30	0	0.68	0.36
	P31	<0.06	7.10	<0.3
	P32	0.07	6.58	0.34
	P33	0	14.84	0.41
Korhogo	P34	<0.06	4.43	1.51
	P35	<0.06	8.34	0.40
	P36	0	5.45	1.36
	P37	0	18.93	0.65
	P38	<0.06	6.51	<0.3
	P39	<0.06	14.46	0.79
	P40	0.291	24.15	0.43
	P41	0.605	14.46	0.37
	P42	0	3.403	0.46
	P43	0	1.39	0.31
	P44	<0.06	7.28	<0.3
	P45	<0.06	48.44	0.41

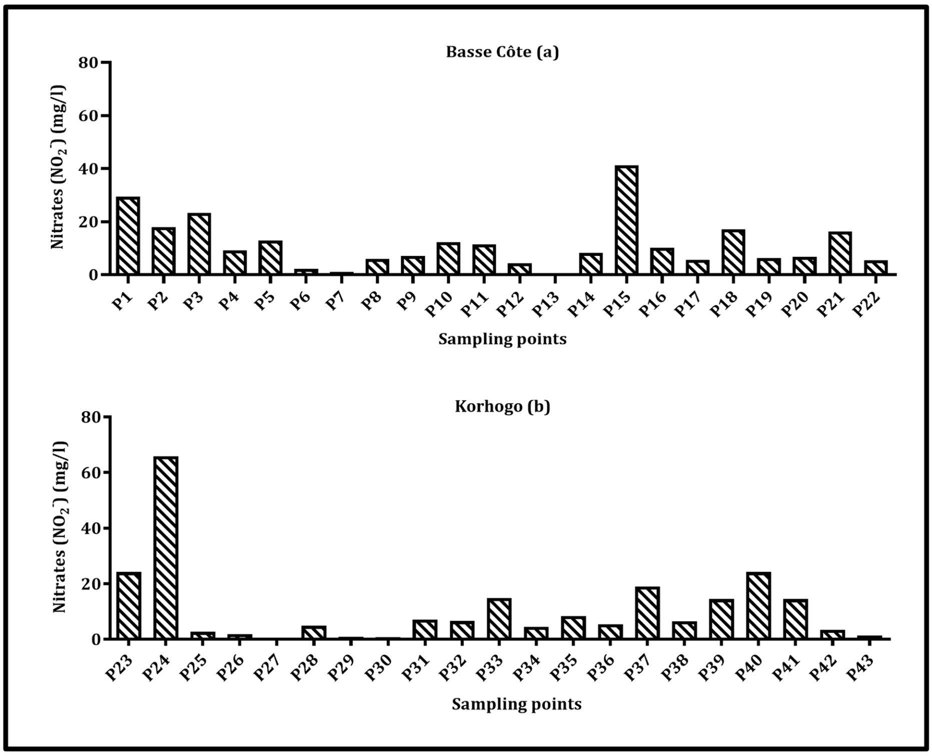

Figure 2. Nitrate concentrations at various sampling points in the regions of Basse Côte (a) and Korhogo (b).

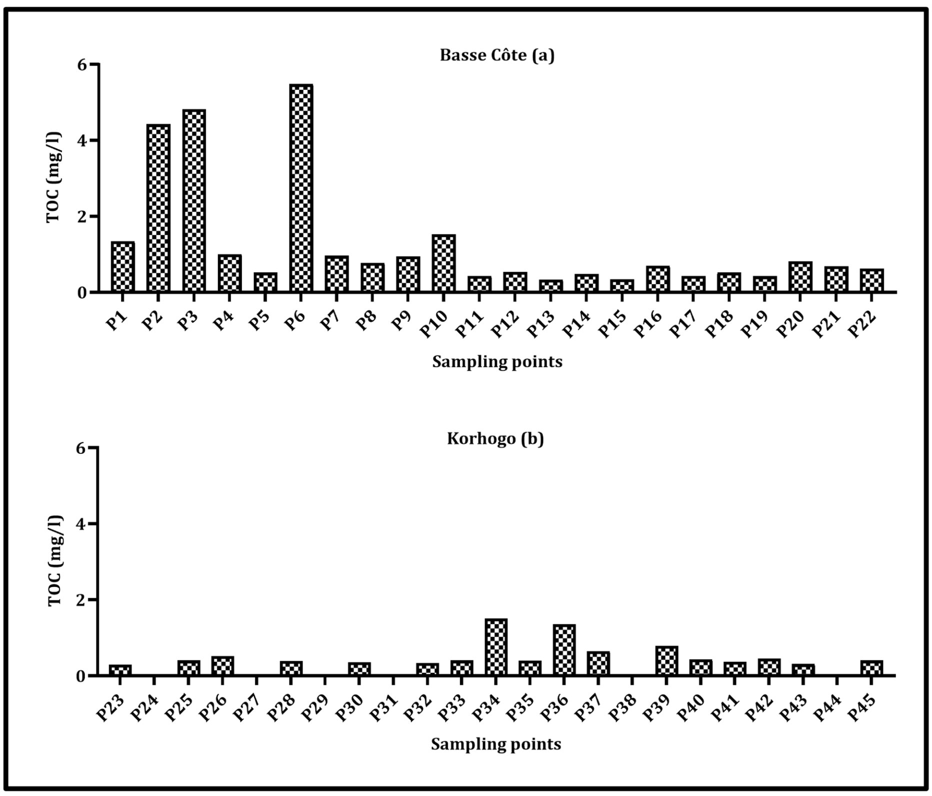

Figure 3. Total organic carbon concentrations at various sampling points in the regions of Basse Côte (a) and Korhogo (b).

3.1.3. Correlation between Chemical and Physical Parameters Measured *in Situ* in the Basse Côte and Korhogo

The nitrate levels obtained in the Basse Côte exhibit a significant positive correlation (r = 0.476; p = 0.025) with conductivity. Similarly, the Total Organic Carbon (TOC) showed a significant positive correlation with pH (r = 0.663; p = 0.001), conductivity (r = 0.530; p = 0.011), and temperature (r = 0.448; p = 0.037). However, a non-significant positive correlation (r = 0.242; p = 0.278) was observed between nitrate levels and temperature. A non-significant negative correlation was also found between nitrate levels and pH (r = −0.033; p = 0.884), as well as with turbidity (r = −0.112; p = 0.620). The study revealed a negative but non-significant correlation (r = −0.015; p = 0.946) between TOC and turbidity (Table 6).

In Korhogo, a non-significant positive correlation was observed between nitrites and temperature (r = 0.476; p = 0.025), conductivity (r = 0.057; p = 0.797), and turbidity (r = 0.294; p = 0.172). However, a non-significant negative correlation was found between nitrites and pH. Additionally, a negative correlation was also observed between nitrates and pH (r = −0.267; p = 0.218), as well as with turbidity (r = −0.045; p = 0.837). Notably, only temperature showed a significant correlation (p = 0.026) with nitrates. Finally, a non-significant positive correlation was observed between nitrates and conductivity (r = 0.395; p = 0.063) (Table 7).

Table 6. Correlation between nitrates, total organic carbon and physical parameters measured *in situ* in the Basse Côte.

Chemical parameters	Physical parameters							
	Temperature (˚C)		pH		Conductivity à 25˚C (µs/cm)		Turbidity (NTU)	
	r	P value	r	P value	r	P value	r	P value
Nitrates	0.242	0.278	−0.033	0.884	0.476	0.025	−0.112	0.620
COT	0.448	0.037	0.663	0.001	0.530	0.011	−0.015	0.946

*p < 0.05; **p < 0.01; ***p < 0.005 ; et ****p < 0.001 vs control.

Table 7. Correlation between nitrites, nitrates, total organic carbon and physical parameters measured *in situ* in the Korhogo.

Chemical Parameters	Physical Parameters							
	Temperature (˚C)		pH		Conductivity (25˚C (µs/cm))		Turbidity (NTU)	
	r	P value	r	P value	r	P value	r	P value
Nitrites	0.018	0.935	−0.296	0.170	0.057	0.797	0.294	0.172
Nitrates	−0.462	0.026	−0.267	0.218	0.395	0.063	−0.045	0.837
COT	−0.278	0.281	−0.22	0.396	−0.353	0.165	0.140	0.593

3.1.4. Ratio of the Sum of Nitrates and Nitrites in Korhogo and the Basse Côte

Figure 4 and **Figure 5** present the sum of ratios between the concentration © of nitrates and nitrites at each sampling point and their guideline value defined by the WHO, obtained using the following formula [47].

$$\frac{C_{nitrates}}{VG_{nitrates}} + \frac{C_{nitrites}}{VG_{nitrites}} \leq 1 \tag{2}$$

The results indicate that the sum of ratios between the concentration of nitrates and nitrites for each sampling point in Basse Côte and Korhogo is less than 1. However, in Korhogo, the results show that the sum of nitrates and nitrites ratios is greater than 1 for points P24 (1.3) and P45 (0.96), with a sum of nitrates and nitrites ratios close to 1.

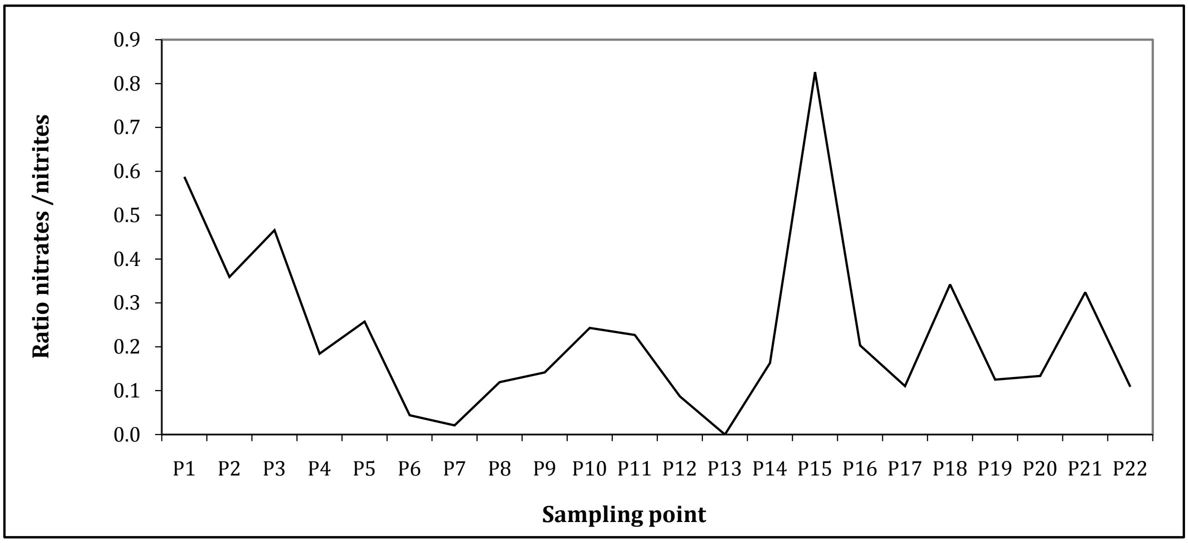

Figure 4. Ratio of the sum of Nitrates and Nitrites in the Basse Côte.

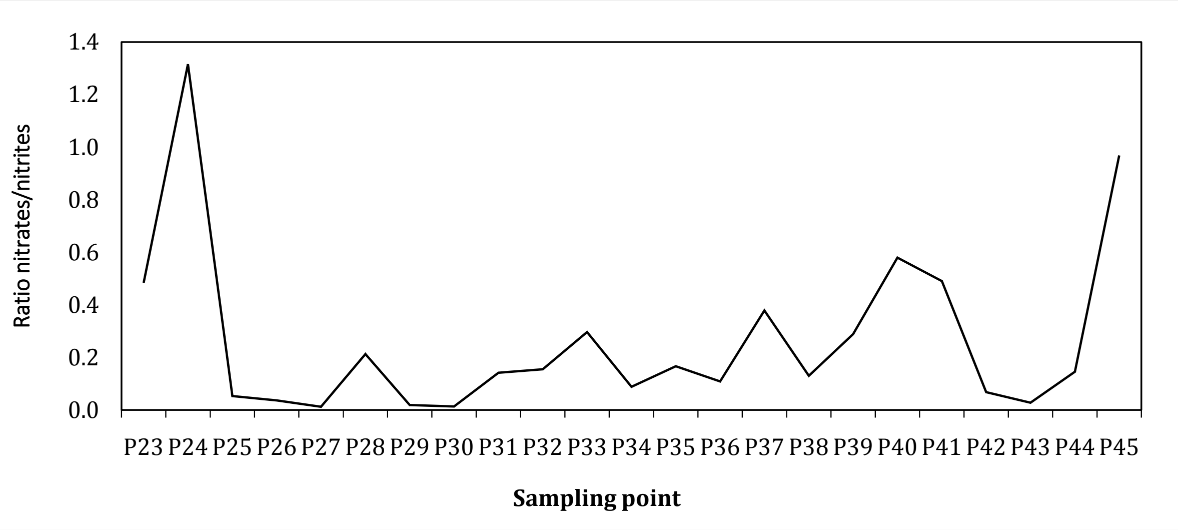

Figure 5. Ratio of the sum of Nitrates and Nitrites in Korhogo.

3.2. Discussion

In this study, the temperatures of the analyzed waters ranged between 20.60˚C and 34.80˚C. However, the average temperature of the water in Korhogo was significantly ($p < 0.0001$) higher than that of the Basse Côte. The temperatures obtained are similar to those reported by other studies on groundwater in West Africa. Indeed, a study in Benin found temperatures ranging from 26˚C to 30˚C with an average of 28˚C [19] [20].

Furthermore, the pH values of the waters ranged between 4.60 and 6.50 with a median of 5.15 and a mean of 5.24 ± 0.12 in the Basse Côte compared to 5.90 and 6.80 in Korhogo with a median of 6.40 and a mean of 6.33 ± 0.05. The difference was significant ($p < 0.0001$) for Korhogo compared to the Basse Côte. The results showed that the waters analyzed in this study were acidic. However, those from the Basse Côte were more acidic than those from Korhogo. The obtained values differ from those of the WHO, as according to this organization, the pH should be between 6.5 - 9, which contradicts this study [21] [22]. The results corroborated those of Lagnika *et al.* (2014) who found averages of 6.53 ± 0.51 and 5.83 ± 0.6 respectively in the groundwater of Cotonou and in the well water of the commune of Pobé in Benin [23] [24]. Indeed, the acidic pH values observed in the Basse Côte region likely reflect the granitic/schistose geology of this area, leading to softer and more acidic groundwater in a similar region of Ghana. The higher pH values in Korhogo correspond to the limestone/dolomitic sedimentary rock formations characteristic of that region [25].

The electrical conductivity at 25˚C ranged from 23.20 to 272.0 µs/cm with a mean of 94.36 ± 16.06 µs/cm and a median of 57.85 µs/cm for Basse Côte water. As for Korhogo, the average conductivity at 25˚C was 171.8 ± 19.36 µs/cm with a median of 163.1 µs/cm and values ranging from 68.40 to 402.0 µs/cm. The average conductivity of Korhogo water was significantly higher ($p = 0.0038$) compared to that of the Basse-Côte. The average conductivity values of the samples in this study are below the WHO standard, which holds a value of 400 µs/cm as the norm. The authors found electrical conductance values between 150.76 and 154.96 µs/cm, which also fell within the standard value for drinking water quality. The higher conductivities in Korhogo indicate more significant mineralization, likely due to the dissolution of carbonate and evaporite rocks in the aquifer. This is consistent with the findings of Yao [26], who measured conductivity of up to 600 µS/cm in groundwater in the Korhogo region [27].

Turbidity in water comes from the presence of finely divided solids that are not detectable by routine methods [28]. In this study, turbidity values ranging from 0.41 to 31.20 and from 0.89 to 72.10 were respectively measured in Basse Côte and Korhogo water, with respective medians of 0.78 NTU and 2.82 NTU. These results showed that the analyzed waters were turbid. The existence of turbidity in water will affect its acceptability by consumers. There is a risk that pathogens may be shielded by turbidity particles and thus escape the action of the disinfectant [29] [30] [31]. The average turbidity value (NTU) of Korhogo water

(8.16 ± 3.23 NTU) was higher than that of the Basse Côte (3.24 ± 1.48 NTU) non-significantly (p = 0.1802). Furthermore, this average turbidity value (NTU) (8.16 ± 3.23 NTU) exceeded the threshold value recommended by the WHO (8 NTU). These results were similar to those of Behailu [10], who found turbidity values exceeding 8 NTU in groundwater samples from the Konso region in Ethiopia [10]-[32]. They concluded that it was necessary to treat the water from this sampling area before use.

The relatively low turbidity values suggest good natural protection of the aquifers studied. Other studies in West Africa have also reported turbidity values on the order of a few NTU in comparable hydrogeological contexts [33] [34] [35]. However, more significant seasonal variations in turbidity are likely during the rainy season [36]. Overall, this study provides useful baseline information on the physical quality of groundwater in these regions of Côte d'Ivoire, consistent with other scientific work in the field [37].

As for chemical parameters, such as nitrates, the values observed in most borehole waters ranged between 1.04 and 41.30 mg/L in Basse Côte water with a mean of 11.80 ± 2.03 mg/L and a median of 9.21 mg/L. Nitrate concentrations ranged from 0.62 to 65.80 mg/L with a mean of 12.49 ± 3.33 mg/L and a median of 6.51 mg/L in Korhogo borehole water. The nitrate concentrations obtained at various sampling points in this study were all below the WHO guideline value (50 mg/L) except for pump P24 in Korhogo with a nitrate concentration of 65.8 mg/L. Furthermore, the presence of nitrites in groundwater in Korhogo, but not in the Basse Côte, likely reflects incomplete denitrification related to local reducing conditions in some Korhogo wells. Athours as Douagui [38], Eblin [39] [40]…, have also observed the presence of nitrites in groundwater in Côte d'Ivoire in similar hydrogeochemical contexts. Nitrate concentrations are generally moderate in both regions, with some exceptional points. These values are consistent with other studies in West Africa that have reported ranges of 1 to 45 mg/L of nitrates in basement and sedimentary aquifers [41] [42]. The observed hotspots could indicate local anthropogenic contamination sources (latrines, waste).

The highest concentrations of total organic carbon (TOC) in some wells in the Basse Côte could originate from the decomposition of organic matter in the groundwater of oxygen-poor granitic/schistose basement aquifers. Studies like those of Ahoussi [43] have also measured high TOC in groundwater in the region, linked to reducing geochemical environments. The results of this study thus provide useful indications of the geochemical evolution and groundwater contamination levels in these regions of Côte d'Ivoire.

The significant positive correlation observed between nitrates and conductivity in Basse Côte groundwater suggests a common geogenic origin for these elements, probably linked to the dissolution of minerals containing these ions in the aquifer. This relationship has also been highlighted in groundwater in the region [44] [45]. The positive correlation between total organic carbon (TOC) and pH, conductivity, and temperature in the Basse Côte indicates that TOC likely originates from the degradation of organic matter under reducing conditions within the aquifer. Similar processes with comparable correlations have been described in groundwater with similar hydrochemical categories in other regions of Côte d'Ivoire [38]-[46].

The absence of a significant correlation between nitrates, pH, and turbidity in the Basse Côte suggests that nitrate sources are primarily geogenic rather than anthropogenic (latrines, waste) and that these ions are not associated with the transport of suspended particles. This result is consistent with the findings in similar basement aquifers in West Africa. The absence of correlation between TOC and turbidity in the Basse Côte also indicates that organic carbon in groundwater is primarily dissolved rather than particulate, reinforcing the hypothesis of an origin linked to the in-situ decomposition of organic matter in the aquifer [47].

4. Health Effect

Nitrate itself is considered of low toxicity. but a part of the ingested nitrate (about 5% - 8%) is transformed into nitrite. the more toxic anion. under the influence of bacteria in the mouth or in the stomach. These ions are quickly absorbed and reach the systemic circulation. The nitrate ion can undergo spontaneously a simple one-electron reduction to yield NO. The maximum contaminant level (MCL) for nitrate in public drinking water supplies in the United States (U.S.) is 10 mg/L as nitrate-nitrogen (NO_3-N). This concentration is approximately equivalent to the World Health Organization (WHO) guideline of 50 mg/L as NO_3 or 11.3 mg/L NO_3-N (multiply NO_3 mg/L) by 0.2258) [48] [49].

5. Conclusion

This study assesses the quality of groundwater from boreholes in the Basse Côte and Korhogo regions of Côte d'Ivoire by measuring the concentrations of nitrates, nitrites, and total organic carbon (TOC). The findings reveal that the groundwater in both regions is acidic, with Korhogo recording higher temperatures and conductivity than the Basse Côte. The relatively low turbidity values suggest good natural protection of the aquifers. Nitrate concentrations are generally moderate in both regions, although there are some exceptions that exceed the WHO guideline value of 50 mg/L. The presence of nitrites in some wells in Korhogo indicates incomplete denitrification, likely due to local reducing conditions. TOC concentrations are higher in the Basse Côte than in Korhogo, which likely reflects the decomposition of organic matter in oxygen-poor granitic/schistose basement aquifers. This study offers valuable baseline information on the geochemical evolution and levels of groundwater contamination in these regions of Côte d'Ivoire, underscoring the need for regular monitoring and treatment of the water before consumption.

Conflicts of Interest

The authors declare no conflicts of interest.

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