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Domestic Water Quality Assessment in Nteingue Community, West Region of Cameroon

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Abstract This study investigated the quality of three main sources of water used in Nteingue community- a village in Santchou municipality of the Menoua division, West Region of Cameroon, in order to determine its suitability for domestic use following World Health Organisation (WHO) guidelines. Inhabitants of this locality consume water from these sources without any prior treatment, which can result in health problems if the water sources are contaminated. Three water sources: a spring in Plantain market, a tap (harnessed spring) in Nteingue market, and an open well in Nteingue-Mbouteuc quarter were sampled in the dry and rainy seasons of 2022 and examined for organoleptic, physicochemical and bacteriological parameters using standard methods recommended by WHO. Water samples had acceptable organoleptic characteristics except for the spring in the rainy season which was clear with tiny dark debris. Results of physical parameters revealed moderately acidic to neutral waters (5.6-7.2) with low mineral content, dissolved solids and turbidity. All major ions were within the WHO guideline values. There were significant seasonal differences observed in the variations of the concentrations of HCO_3^- and K^+ ($p < 0.05$). The water sources were $Ca^{2+} - Mg^{2+} - Cl^- - SO_4^{2-}$ type in both seasons, which are typical of ground water resources. Sampled waters were also acceptable based on water quality indices, exception being the open well which had a poor quality index in the rainy season. Faecal coliforms and specific bacteria (*Escherichia coli*, *Enterobacter*, *Streptococcus*, *Vibrio*, *Salmonella*, *Staphylococcus*, *Streptococcus*, and *Shigella spp*) were identified in all sampled waters, suggesting recent contamination of the sources by human or animal faeces. The sources were unfit for domestic use and thus, exposed the population to water-borne diseases such as typhoid, diarrhoea and dysentery. Hence, home treatment methods such as chlorination, filtration, and boiling should be implemented prior to consumption.

Keywords: *domestic water, water quality, faecal coliforms, Nteingue*

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1. Introduction

Water is the second most important need for life to exist after air [1]. It covers about 80% of the Earth's surface, but availability of freshwater supply has increasingly become a major problem [2]. Access to fresh water remains a major challenge for millions of households on the African continent, and more particularly, those located in its sub-Saharan part; meanwhile, it stands as one of the main objectives for sustainable development [3].

Deficiency in drinking water supply is related to several factors, which include poverty, rural exodus, population growth, current climate change and variability, and lack of investment in the water sector (production, treatment and distribution) [4,5]. Although Africa has abundant sources of fresh water, millions of rural households across the continent do not have access to clean drinking water. This has caused the population to rely on unhealthy water sources which when consumed, causes waterborne diseases such as cholera and diarrhoea, which kills over 2000 under-five children across the globe, every day. Majority of deaths resulting from diarrhoea are said to occur in sub-Saharan Africa [6]. Drinking water quality has an impact on health and therefore, the effective monitoring, assessment, and treatment of drinking water sources are important for the wellbeing of the public and to allow the implementation of a preventive approach to manage drinking water quality [7].

National drinking water standards often stipulate the maximum permissible concentration of contaminants in drinking water, and at a global scale, the World Health Organization (WHO) guidelines provide recommendations for managing the risk of hazards that may compromise the safety of drinking water [8].

Today, the major difficulty confronted by Cameroonians is not access to water but more precisely, access to potable water for domestic use. Water-related diseases represent about two-thirds of all diseases in this country; responsible for approximately 50% of death cases recorded annually [9,10]. The level of improved drinking water sources and sanitation facilities in semi-urban and rural communities of the country was placed at 49% (WHO, 2015). In rural areas where conventional water network is absent, the population rely on community taps, surface, and groundwater sources for domestic use. The quality of these sources is largely determined by both natural processes (dissolution and precipitation of minerals, groundwater velocity, quality of recharge waters, and interaction with other types of water aquifers) and anthropogenic activities [2].

Nteingue community is not adequately supplied with good quality water by the national water supply to meet the ever-increasing clean water demand, which is indispensable to the local population's continued existence. The inhabitants are therefore forced to use the available sources which are hand-dug wells, flowing springs, and community taps for domestic purposes. The main spring is surrounded by agricultural farm land and forest. The available taps distributing constructed well water are found in very few quarters, and water from it is sometimes coloured. Most of the wells are shallow, not properly covered, very close to buildings and pit toilets. These sources have the possibility of being contaminated by natural and anthropogenic pollutants. Domestic use of these doubtful water sources may pose a serious health concerns since they may lead to water-borne diseases. Information on the organoleptic, physicochemical, and bacteriological properties of these water sources has not been documented. Therefore, there is the need for proper assessment and monitoring of water from these sources. This study was therefore aimed to examine the physicochemical and bacteriological characteristics of water from three main sources in Nteingue in order to ascertain their suitability for domestic use based on WHO guidelines for drinking water quality.

2. Materials and Methods

2.1. Geographical Description of the Sampling Site

Nteingue is a village in Santchou subdivision of the Menoua division in the West Region of Cameroon. It is situated along the Dschang-Douala highway, some 20 km from Dschang, 9 km from Santchou town, and 182 km from Douala. The land stretches over 12 km^2 and culminates at about 1450 m altitude, between the coordinates longitude 10°30'00" -10°95'00 E and latitude 5°21'00"-5°83'00" N. It has a population of about 5000 inhabitants. It is bounded by neighboring villages of Santchou sub division; to the North by Fotetsa, to the South by Fomella, to the south West by Fombap, and to the West by Fotochi. [11].

Nteingue is endowed with a rich climate marked by two distinct seasons; the rainy and dry seasons. The rainy season starts from mid-March to mid-November with peaks in August and September. The dry season is from mid-November to mid-March with its peak from December to February, which is common over the southern part of the national territory. Nteingue has the subequatorial climate. The main economic activity of the population is farming. Nteingue village has three natural water resources such as groundwater (springs, wells), surface water (streams and rivers), and rainfall.

2.2. Sample Collection and Preservation

Water samples were collected from three main sources (well, natural spring, and harnessed spring(tap)) in Nteingue village (Figure 1). Each water source was sampled twice (dry season and rainy season) in order to investigate the effect of season on the water quality. Sampling points were chosen in relation to their use by the population. The samples were collected using clean and sterilized 0.5 L polyethylene containers which were all labelled as A (spring), B (tap), and C (well). The containers were rinsed with water to be sampled from each source several times before collecting the required sample volume. The collections were done in the morning and the samples were packaged in a cooler containing ice in order to maintain the temperature around 4°C to minimize physicochemical and bacteriological changes. Finally, the samples were transported to the Research Unit of Animal Physiology and Microbiology and Research Unit of Soil Analysis and Environmental Chemistry, in the University of Dschang, Cameroon on that same day for preservation and analyses. A Global Positioning System (GPS) was used to locate the study sites geographically. The coordinates are presented in Table 1.

Table 1. Geographical coordinates of sampling points

Sampling point name	Source type	Sample code	GPS coordinates	Elevation (m)
Plantain market	Spring	A	5°21'53"N, 10°00'28"E	728.472
Nteingue market	Tap	B	5°20'33"N, 10°00'40"E	756.514
Nteingue mbouteuc	Well	C	5°19'46"N, 10°00'43"E	728.472

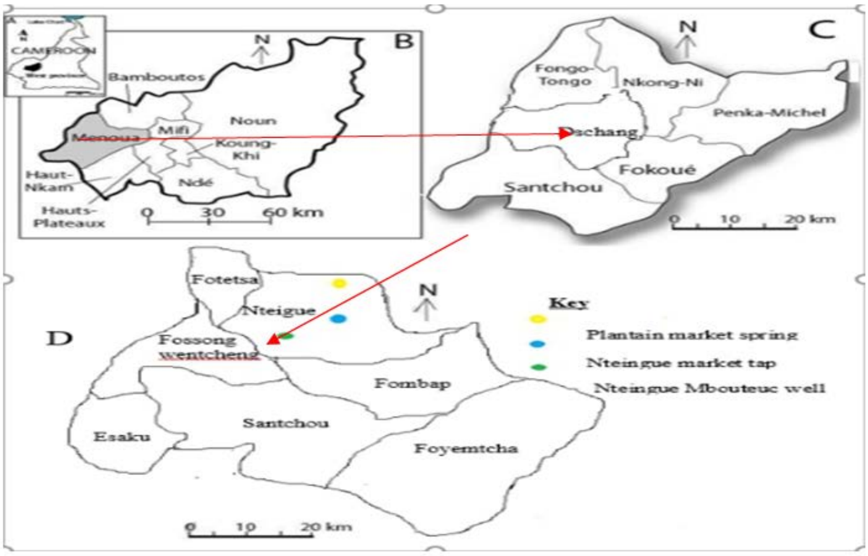

Figure 1. (A) Map of Cameroon, indicating the map of West region, (B) map of West region indicating the map of Menoua, (C) map of Menoua showing the map of Santchou, (D) map of Santchtou indicating Nteinue village with sampling points [19]

2.3. Analyses

2.3.1. Physicochemical Analyses

pH, electrical conductivity (EC), and total dissolved solids (TDS) were determined in situ with a calibrated multimeter, HANNAH198128. Turbidity was measured using a turbidimeter (Model DRT 100B, MF scientific, Inc). Chloride content was determined by the argentometric method. Nitrate and ammonium were determined by Kjeldahl's distillation method. Phosphate was determined by UV-visible spectrophotometric analysis. Bicarbonate was determined by acid-base titration and sulphate by gravimetric analysis. Ca and Mg ions were determined by complexometric titration, while Na and K were determined by flame photometry. All analyses were done following the methods described by [8] and [12]. Total permanent water hardness (TH) expressed as equivalent of $CaCO_3$ was calculated following formula 1 [13].

$$TH = 2.5[Ca^{2+}] + 4.1[Mg^{2+}] \quad (1)$$

Where

TH = Total permanent hardness as $CaCO_3$ in mg/L.

$[Ca^{2+}]$ = Ca^{2+} concentration in mg/L.

$[Mg^{2+}]$ = Mg^{2+} concentration in mg/L.

The interpretation of water type with respect to TH was done by using Table 2.

Table 2. Interpretation of water type based on its total hardness [8]

Concentration in mg/L as $CaCO_3$	Water type
0 - 60 mg/L	Soft
60 -120 mg/L	moderately hard
120 -180 mg/L	Hard
TH >180 mg/L	very hard

2.3.2. Water Quality Index (WQI)

Water Quality Index (WQI) is one of the most effective tools to monitor surface water as well as ground water pollution and can be used efficiently in the implementation of water quality upgrading programmes [14]. The WQI model simplifies the presentation of the results of an analysis related to a water body as it summarises in one value a series of parameters analysed [14]. WQI also eases the comparison between different sampling sites and events. WQI was calculated using the weighted Arithmetic Index Method [14,15]. In this study, the parameters used for the calculation of WQI include pH, EC, Turbidity, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, HCO_3^-, NO_3^-, SO_4^{2-} and PO_4^{3-}. Calculation was done using the WHO standards and the following steps below.

In the first step, the unit weight (Wi) for each water quality parameter was determined using the following formula:

$$W_i = \frac{K}{S_i} \quad (2)$$

Where

S_i = standard value of i^{th} parameter recommended by WHO,

K = proportionality constant which is calculated by using equation 3:

$$K = \frac{1}{\sum_{i=1}^{n}\left(\frac{1}{S_i}\right)} \quad (3)$$

The inverse of the sum of inverses of standard parameters was used in order to make the parameters expressed by large numbers to weigh less in equation 5. In the second step, a quality rating or sub-index (qi) was computed for each of the parameters using equation 4:

$$q_i = \frac{V_i - V_0}{S_i - V_0} \times 100 \quad (4)$$

Where

V_i = estimated value of i^{th} parameter in the analysed water sample,

V_0 = ideal value of this parameter in pure water (it is zero for all parameters except pH = 7.0 and DO = 14.6 mg/L),

S_i = recommended standard value of i^{th} parameter given by WHO.

In the final step, the overall WQI was calculated by using equation 5:

$$WQI = \frac{\sum_{i=1}^{n} q_i W_i}{\sum_{i=1}^{n} W_i} \quad (5)$$

A reference WQI table (Table 3) was used to deduce the sampled water status.

Table 3. Water Quality Index and Status of water quality [14]

WQI	Water Quality Status	Grade
0-25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Very poor	D
>100	Unsuitable for drinking	E

2.3.3. Hydrochemical Facies

Piper trilinear diagrams were drawn using chemical properties to classify the analysed water sources into various hydro-chemical facies [16].

2.3.4. Statistical Analysis

Paired sample T-test was performed at 95% confidence interval to verify if there exist any significant differences in the mean parameters due to seasonal changes or spatial variation, and Pearson correlation was used to verify the relations between parameters. Statistical Package for Social Sciences (SPSS) version 20.0 was used for statistical analysis.

3. Results and Discussion

3.1. Organoleptic Parameters: Appearance, Colour and Odour

Results of organoleptic parameters showed that all water samples were clean, clear, and colourless for both seasons except sample C that had tiny dark debris in the wet season (Table 4).

The presence of debris in the well is a sign of other contaminants [8] and could be due to atmospheric deposition since it was exposed to the surroundings. This is justified by the high value of turbidity (10.8 NTU) that is above the WHO standard (5 NTU). The good organoleptic properties of most of these sources could be justified by the fact that these are ground waters are naturally filtered as they are recharged by precipitation. All the samples met the WHO requirement for safe drinking water except sample C in the rainy season that will require proper filtration before use. However, at this level, there was no assurance as good domestic water must not only be clean, clear, and odourless according to WHO, but should possess good physical, chemical, and bacteriological qualities [7,15].

3.2. Physical Parameters

Physical parameters are presented in Table 5.

3.2.1. pH

Water pH varied between 6.8 and 7.2 with a maximum mean of 7.05± 0.21 obtained from the spring source in the dry season (Table 5). The pH of the samples in both seasons were not significantly different ($p>0.05$). The strong positive correlation observed between pH and *E. coli* ($r = 0.999$; $p < 0.01$) and between pH, *Enterobacteria*, *Streptococcus* spp, *Salmonella* spp and *Shigella* spp ($r = 1$, $p < 0.01$) suggested that bacteria growth in the water sources is highly dependent on pH variations. All pH values were within WHO permissible limits (6.5-8.5). Regarding the health aspect, no extreme pH values which may result in health risk was recorded. Hence, the water sources were acceptable for drinking. The pH values obtained in this study are in disagreement with 6.1-6.6 recorded by [17] in Santchou, a neighbouring town. The study attributed the pH variation in the area to the lithology of the aquifer system as well as hydrogeochemical processes operating in the aquifer.

Table 4. Organoleptic characteristics of sampled waters

	Colour		Appearance		Odour	
Code	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Spring(A)	Colourless	Colourless	Clear and Clean	Clear and Clean	Odourless	Odourless
Tap (B)	Colourless	Colourless	Clear and Clean	Clear and Clean	Odourless	Odourless
Well (C)	Colourless	Colourless	Clear and Clean	Clear with tiny dark debris	Odourless	Odourless
WHO guide	colourless		Clear and clean		odourless	

Table 5. Statistical summary of physical parameters of sampled waters

Code	Spring (A)				Tap (B)				Well (C)				
Parameter	Dry season	Wet season	Mean	SD	Dry season	Wet season	Mean	SD	Dry season	Wet season	Mean	SD	WHO
pH	7.2	6.9	7.05	0.21	6.8	7.1	6.95	0.21	6.8	6.9	6.85	0.07	6.5 - 8.5
EC (µS/cm)	30	50	40.00	14.14	50	60	55.00	7.07	90	160	125.00	49.50	1000
TDS (mg/L)	20.1	33.5	26.8	9.48	33.5	40.2	36.85	4.74	60.3	107.2	83.75	33.16	500
Turbidity (NTU)	6.5	2.4	4.45	2.90	1.1	0.1	0.60	0.71	1.3	10.8	6.05	6.72	5

SD= standard deviation

3.2.2. Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Electrical conductivity ranged from 30 to 90 µS/cm in the dry season, and 50 to 160 µS/cm in the wet season with a maximum mean value of 125 µS/cm recorded in the well, while TDS ranged between 20.10 and 60.30 mg/L in the dry season and between 33.5 and 107.2 mg/L in the wet season, with a maximum mean value of 83.75±33.16 mg/L in the well (Table 5). No significant differences in mean EC and TDS values were observed between seasons (p>0.05). Low EC and TDS values compared to the WHO guideline values of 1000 µS/cm and 500 mg/L, respectively, suggest low mineralized water with little dissolved solids [18]. A strong positive correlation observed between EC and TDS (r_1= 1.00, p<0.01) is due to the direct proportional relationship between both parameters, given that TDS arises mainly from inorganic salts in solution [15]. Similar low EC and TDS values have been recorded in this area by [17] and [19] and elsewhere in Cameroon by [15] and [20].

3.2.3. Turbidity

Turbidity ranged from 1.1 to 6.5 NTU in the dry season and 0.1 to 10.8 NTU in the wet season with a maximum mean value of 6.05 NTU recorded in the well (Table 5). There were no significant differences in turbidity between seasons (p>0.05). The spring and well had turbidity values of 6.5 NTU and 10.8 NTU in the dry and wet seasons, respectively, that were above the WHO guideline value (5 NTU). High turbidity recorded in the spring during the dry season may be due to reduced or no precipitation, low flow velocity, high temperatures and high evapotranspiration. On the other hand, the increase in turbidity of the well during the wet season could be attributed to the presence of clay and other particulate matter transported by water. Water from these sources were thus of doubtful quality and consequently unfit for human consumption with respect to turbidity, given that the presence of particulate materials contributes to bacteria and viruses' growth and protects them against disinfection [8,15]. The contribution of turbidity to microbial growth was evident through the strong positive correlation between turbidity, *Enterobacteria*, *Salmonella* spp, and *Shigella* spp (r = 0.99, p<0.01). Maximum turbidity values recorded in this study were low compared to the maximum values of 13.1 NTU and 65.2 NTU reported in this area in the dry and wet seasons, respectively [17].

3.3. Chemical Parameters

Chemical parameters analysed included major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}), major anions (NO_3^-, HCO_3^-, SO_4^{2-} and Cl^-) and nutrients (NH_4^+ and PO_4^{3-}). A summary of chemical parameters is presented in Table 6.

3.3.1. Sodium and Potassium

Sodium ranged from 0.32 to 90 0.80 mg/L in the dry season, and 0.44 to 1.49 mg/L in the wet season with a maximum mean value of 1.15± 0.49 mg/L recorded in the well, though there was no significant difference (p>0.05) in the seasonal variation. The strong negative correlation between sodium and pH (r= -1.00, p<0.01), suggests that acidic water favours the dissolution of this ion from rocks [17]. Potassium ranged between 2.19 and 3.15 mg/L in the dry season and between 0.86 and 2.36 mg/L with a maximum mean value of 2.76± 0.56 mg/L also recorded in the well (Table 6), with a significant decrease in mean concentration in the wet season (p<0.05), attributable to the effects of rain [17]. All water sources had very low Na^+ and K^+ concentrations compared to the WHO set standards of 200 mg/L for both ions. Low sodium ions in the sampled waters could be as a result of low sodium in the geological formations of the study area, as it generally originates from the weathering of rock salt like sodium silicate (Na_2SiO_3) [8,15,20], its common source being the dissolution of Albite ($NaAlSi_3O_8$).

Table 6. Statistical summary of chemical parameters of sampled waters

Code	Spring (A)				Tap (B)				Well (C)				
Parameter	Dry season	Wet season	Mean	SD	Dry season	Wet season	Mean	SD	Dry season	Wet season	Mean	SD	WHO
Ca^{2+} (mg/L)	19.60	31.80	25.70	8.63	21.20	23.00	22.10	1.27	18.80	25.80	22.30	4.95	75
Mg^{2+} (mg/L)	8.82	15.88	12.35	4.99	4.93	7.30	6.12	1.68	18.54	22.54	20.54	2.83	30
Na^+ (mg/L)	0.32	0.44	0.38	0.08	0.80	0.44	0.62	0.25	0.80	1.49	1.15	0.49	200
K^+ (mg/L)	2.19	0.86	1.53	0.94	2.19	1.13	1.66	0.75	3.15	2.36	2.76	0.56	200
Cl^- (mg/L)	24.85	35.50	30.18	7.53	35.50	35.50	35.50	ND	53.25	31.95	42.60	15.06	250
HCO_3^- (mg/L)	91.50	128.10	109.80	25.88	48.80	122.00	85.40	51.76	61.00	122.00	91.50	43.13	1000
SO_4^{2-} (mg/L)	30.50	48.50	39.50	12.73	81.50	71.50	76.50	7.07	100.50	164.00	132.25	44.90	250
NO_3^- (mg/L)	12.4	5.21	8.81	5.08	7.44	6.15	6.80	0.91	4.96	4.98	4.97	0.01	50
NH_4^+ (mg/L)	3.70	0.25	1.98	2.44	9.24	0.71	4.98	6.03	5.54	0.61	3.08	3.49	30
PO_4^{3-} (mg/L)	0.01	ND	0.01	0.01	0.04	ND	0.02	0.03	0.01	ND	0.01	0.01	5

Low Sodium concentrations could also be attributed to the absence of industrial activity in the study area [8]. Similar low sodium has been recorded in the neighbouring Santchou town [17] and elsewhere in Cameroon [24,25]. Although sodium is a necessary dietary component, its low concentration has no health implications as high sodium consumption is a long-term factor responsible for the genesis of arterial hypertension [26]. Potassium is one of the most important minerals in the body that helps in regulating fluid's balance, muscle contractions, and nerve signals. Its low concentration in the studied waters may be due to its low geochemical mobility in the soils [10,27]. The low potassium is in contrast to that recorded by [17] in the neighbouring Santchou town; its possible origin being the disintegration of silicate minerals like orthoclase, microcline, albite and muscovite and improper application of potassium fertilizers and sewage disposal [17]. [28] reported potassium concentrations between 5.54 mg/L and 12.82 mg/L in peri urban areas around Mount Cameroon which was attributed to the geology of the area. Relatively low potassium concentrations compared to [17] have equally been recorded in other African countries [21,29].

3.3.2. Calcium and Magnesium Ions

Calcium and magnesium are the primary ions responsible for water hardness. Calcium ion concentrations ranged from 18.80 to 21.20 mg/L in the dry season and 23.00 to 31.80 mg/L in the wet season with a maximum mean value of 25.70± 8.63 mg/L recorded in the spring, while Mg^{2+} ranged from 4.93 to 18.54 mg/L in the dry season and 7.30 to 22.54 mg/L in the wet season with a maximum mean value of 20.54±2.83 mg/L recorded in the well. Ca^{2+} and Mg^{2+} did not vary significantly with season ($p > 0.05$).

The relative abundance of the major cations was as follows: $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ (Figure 2). The presence of Ca^{2+} and Mg^{2+} as dominant cations suggests the occurrence of limestone and chalk sediments in the study area [26]. Both ions may also originate from igneous rocks, particularly basalts [30], their main source being the weathering of calco-sodic feldspar, olivine, pyroxene, and hornblende in the basic rock [31,32,33].

Based on the WHO guideline values of 75 mg/L and 30 mg/L for calcium and magnesium ions, respectively, the sampled waters were all fit for human consumption. However, the total hardness (TH) in mg/L as $CaCO_3$ showed that the well in both seasons and the spring in the wet season were hard (120 mg/L ≤TH<180 mg/L), while the spring in the dry season and tap in the wet season were moderately hard (60 mg/L≤TH < 120 mg/L) (Table 7).

Calcium concentrations have been recorded within the same range in ground water in the neighbouring Santchou town by [17]. However, the study recorded very high concentrations of magnesium ranging between 68.9 and 262.5 mg/L in the dry season. Though some consumers may tolerate total hardness in excess of 500 mg/L, it should be noted that excess intakes of calcium have been associated with increased risk of nephrolithiasis (kidney stones) [20]. Moreover, drinking water with high magnesium content will have a laxative effect [26]. In addition, water with hardness above 200 mg/L will lead to lathering impairment in laundry and bathing and [26,34].

3.3.3. Ammonium Ion

Ammonium ions ranged from 2.70 to 9.24 mg/L in the dry season and 0.25 to 0.61 mg/L in the wet season with a maximum mean of 4.98± 6.06 mg/L recorded in the tap, without any significant differences between mean values of seasons ($p>0.05$). Ammonium ions in the waters could be from biological breakdown of domestic and agricultural wastes; thus, indicating bacterial, sewage, and animal waste contamination from nearby farms and homes [26]. However, the concentrations were far below the permissible limit of 30 mg/L set by the WHO. Ammonium concentrations recorded are in accordance with values recorded by [35] in the ground waters of Bamenda, and [21] in Treichville municipality (Abidjan, Côte d'Ivoire). Contrarily, [36] reported very high ammonium concentrations in groundwater in Lomé, Togo, attributed to contamination from sources such as pit latrines, dumpsites, septic tanks, sewer leakage, sewage effluent, and sewage sludge.

Table 7. Total water hardness (TH) in sampled sources

	Spring		Tap		Well	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
TH	85.16	144.61	73.21	87.43	123.01	156.91
Water type	Moderately hard	Hard	Moderately hard	Moderately hard	Hard	Hard

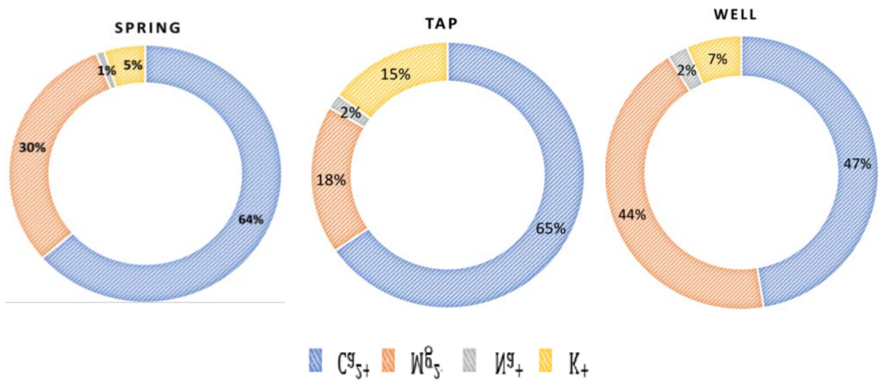

Figure 2. Relative abundance of major cations in sampled waters

3.3.4. Bicarbonate Ion

The concentration of HCO_3^- ranged from 48.80 to 91.50 mg/L in the dry season and 122.0 to 128.10 mg/L in the rainy season with a maximum mean of 109.0± 25.88 mg/L and recorded in the spring. Mean HCO_3^- concentrations significantly increased in the wet season ($p<0.05$).

The relative abundance of the major anions in the water sources were as follows: $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$ in the spring and tap and $SO_4^{2-} > HCO_3^- > Cl^- > NO_3^-$ in the well (Figure 3). Bicarbonate was the most abundant anion in the waters. Its presence in the water sources could be as the result of the partitioning of CO_2 from the atmosphere in the wet season [37] and the weathering of iron rich minerals such as olivine [38]. However, the concentrations were very low compared to the WHO guideline value of 1000 mg/L, indicating that the water sources are of good quality with respect to bicarbonate concentration. The low content of these sources is possibly due to the process of auto-purification of water. [18] Also recorded HCO_3^- values between 2.5 and 91.1 mg/L in some bore holes and wells, which were associated with its possible igneous origin. [11] made a similar observation but with the exception of one point (well) with bicarbonate content as high as 1200 mg/L in the Dschang municipality. HCO_3^- is necessary as it constitutes an important buffer system which helps in lowering the acidity of water [39].

3.3.5. Sulphate Ion

Sulphate ranged from 30.5 to 100.5 mg/L in the dry season and 48.5 to 164.0 mg/L in the wet season with a maximum mean concentration of 132.25± 44.90 mg/L recorded in the well. Mean sulphate did not vary significantly with season ($p>0.05$). The presence of sulphate in water can be as a result of acid rain, the dissolution of evaporitic sedimentary rocks such as gypsum ($CaSO_4.2H_2O$) and pyrite(FeS), and the use of artificial fertilizer and detergents [11]. All samples had sulphate concentrations below the permissible limit (250 mg/L) and therefore posed no health risk to consumers.

3.3.6. Nitrate Ion

The nitrate concentration ranged from 4.96 to 12.40 mg/L in the dry season and 4.98 to 5.21 mg/L in the rainy season with a maximum average value of 8.81± 5.08mg/L. There was no significant difference in nitrate concentration between seasons ($p>0.05$). The main sources of nitrate in groundwater could be attributed to agricultural practices such as the application of nitrogenous fertilizers and manures, wastewater disposal, leaching from natural vegetation and seepage from latrines, pit toilets or septic tanks. Interest is centred on nitrate mostly because high nitrate levels in waters have been reported to be responsible for the "blue baby" syndrome (methaemoglobinaemia) and typhoid effects [26]. Similar low nitrates have been recorded in this area by [17]. The nitrate concentrations were below the WHO permissible limit (50 mg/L). Therefore, with respect to nitrate, all sources in both seasons pose no health hazards.

3.3.7. Chloride Ions

Chloride concentrations ranged from 24.85 to 53.25 mg/L in the dry season and from 31.95 to 35.5 mg/L in the wet season with a maximum mean value of 42.66± 15.06 mg/L recorded in the well. Chloride concentrations did not vary significantly with season. The concentrations were far below the WHO guideline value of 250 mg/L, indicating no Cl^- pollution. Low Cl^- suggest low minerals such as sodalite, apatite, feldspathoids, and halite in the study area, as Cl^- is naturally leached from these minerals into soil and water by weathering [23,40]. Low Cl^- had been recorded elsewhere in Cameroon [30,33,39,41]. However, [17] recorded relatively high chloride values in this area with some values above the WHO guideline value.

3.3.8. Phosphate Ions

Phosphate ranged from 0.01 to 0.04 mg/L in the dry season and was non-detectable in the wet season. The concentrations were below the WHO limits of 5 mg/L. The presence of phosphate in water could result from natural decomposition of rocks and minerals, erosion, and sedimentation [42]. Its low concentration in the dry season and its absence in the wet season could be due to its sorption to organic colloids. Phosphate's concentrations recorded in this study are in agreement with the findings of [17] in this area.

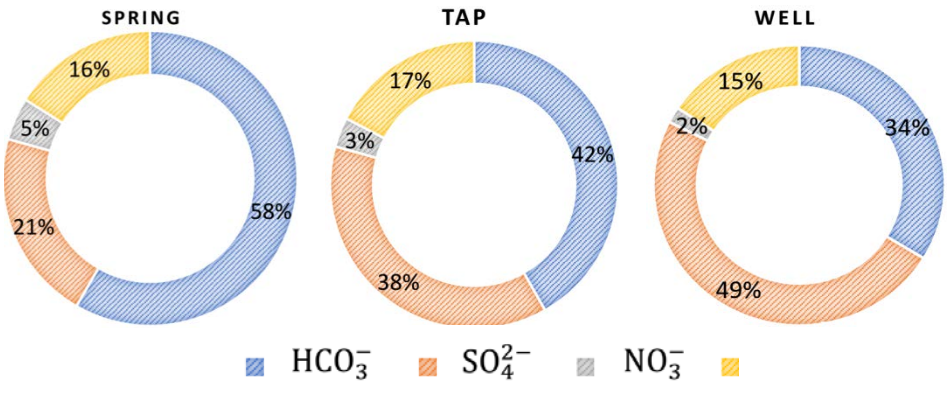

Figure 3. Relative abundance of major anions in sampled waters

3.4. Hydrochemical Facies

The concentrations (mg/L) of the major cationic and anionic constituents of the water samples were plotted on a Piper trilinear diagram to determine the water types (Figure 4). The ternary diagram in the lower left section representing cations showed that alkaline earth metal ions, $Ca^{2+} + Mg^{2+}$ exceeded alkali metal ions, $Na^{+} + K^{+}$. Meanwhile, the ternary diagram in the lower right representing anions showed no dominant anions in the waters in both seasons. The dominance of calcium and magnesium in groundwater samples suggested an inverse ion exchange process during which Ca from the aquifer matrix was exchanged by Na from the groundwater [43]. The plot of physicochemical data on the diamond-shaped trilinear diagram, which is a matrix transformation of the two ternary diagrams, revealed that the waters were $Ca^{2+} - Mg^{2+} - Cl^{-} - SO_4^{2-}$ type in both seasons, which are typical of ground waters.

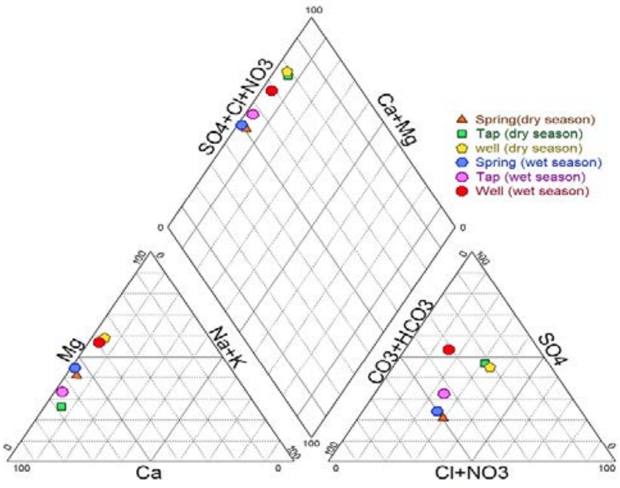

Figure 4. Piper's diagram showing the hydrochemical facies of the studied ground waters

3.5. Water Quality Index

The Water Quality Index (WQI) values and the status of water quality for the water samples are presented in Table 8. Based on the computed WQI, the tap in both seasons, spring in the wet season and well in the dry season were excellent (grade A, WQI<50), while the spring was good in the dry season (grade B) and well graded as poor in the rainy season (grade C). It is important to note that WQI may not convey sufficient information about the real quality situation of water since the covering or overstressing of a single bad parameter value can give deceptive information about the water quality. Moreover, the bacteriological quality, which is not included in the calculations, limits the applicability of WQI. This is because water with excellent WQI grade but having poor bacteriological quality will still be unsuitable for consumption.

Table 8. Water quality indices for sampled sources

	WQI		Water type	
Sample	**Dry season**	**Wet season**	**Dry season**	**Wet season**
Spring	51.61	14.78	Good (B)	Excellent (A)
Tap	2.57	7.35	Excellent (A)	Excellent (A)
Well	5.18	67.52	Excellent (A)	Poor (C)

3.6. Bacteriological Parameters

Bacteriological analysis revealed the presence of faecal coliforms in all water sources, with the most probable numbers ranging from 03 to 40/100 mL in the dry season and 10 to 35/100 mL in the rainy season (Table 9). Specific analyses led to the isolation of specific bacteria such as *Enteroibacteria, E. coli, Streptococcus spp, Salmonella spp, Shigella spp,* and *Staphylococcus spp,* with colony counts in the following ranges: *Enterobacteria* (05 – 88 CFU/mL in the dry season and 15 – 60 CFU/mL in the rainy season), *E. coli* (03 – 40 CFU/mL in the dry season and 10 – 35 CFU/mL in rainy season), *Streptococcus* (02 – 10 CFU/mL in the dry season and 05 – 20 CFU/mL in rainy season), *Salmonella* (00 – 20 CFU/mL in the dry season and 00 – 10CFU/mL in rainy season), *Shigella* (00– 01 CFU/mL in the dry season and 00-05 CFU/mL in rainy season) and *Staphylococcus* (03–15 CFU/mL in the dry season and 05 – 10 CFU/mL in rainy season) as shown in Table 10. There were no significant differences in the mean colony counts of bacteria between the two seasons (p>0.05).

Table 9. Results of Most Probable Number (MNP) of coliforms in sampled waters

Volume of sample in each bottle	**50 mL**		**10 mL**		**1 mL**		**Most probable number of coliforms in 100 mL of original water (MPN/100 mL).**			
Number of bottles used	**1**		**5**		**5**		**Mean count**		**category**	
Sample	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Spring	1	1	4	4	5	4	40	35	C	C
Tap	1	1	1	1	1	3	5	09	B	B
Well	0	1	1	3	2	3	3	20	B	C

A= Excellent, B= Acceptable; low risk; C= Unacceptable high risk; D= grossly polluted

Table 10. Specific microbes isolated (colony forming units/mL) in sampled waters

Sample	**Enterobacteria spp**		**E.coli**		**Streptococcus spp**		**Salmonella spp**		**Shigella spp**		**Staphylococcus spp**	
	Jan	April	Jan	April	Jan	April	Jan	April	Jan	April	Jan	April
Spring	88	60	40	35	10	20	20	10	01	00	15	10
Tap	05	15	05	10	00	05	00	00	00	05	10	00
Well	05	35	03	20	02	05	00	10	00	00	03	05
WHO		0		0		0		0		0		0

Based on classifications [44], the spring showed a high risk during both seasons and was thus unacceptable (category C), the tap was acceptable as the risk was minimal (Category B) in both seasons while the well which showed low risk in the dry season, was unacceptable in the rainy season.

The presence of faecal coliforms and *E. coli* - indicators of faecal pollution, and other specific pathogenic bacteria suggest recent contamination of water sources by human or animal faeces. Given that faecal coliforms such as *E. coli* are prevalent in the digestive tracts of warm-blooded animals, their presence in water is definite evidence of faecal contamination [40]. A similar observation was made by [45] in some selected communities in South-western Nigeria.

World Health Organisation (WHO) guidelines recommend no bacteria of faecal origin in drinking water. Thus, all sources were unfit for domestic uses such as drinking and bathing and may have little or no effect on cooking if the water is boiled above 70°C for more than 30 minutes. However, looking at the level of contamination, some sources were acceptable for consumption (category B). Comparable faecal coliform counts have equally been recorded in this area [17] and [19], in other parts of Cameroon by [15,20,25,33,39,46,47] and elsewhere in Africa by [36,48]. [49] also reported high faecal coliforms in 83% of untreated water sources in Brazil, which was associated with leachate from animal manure.

4. Conclusion

The water samples had acceptable organoleptic characteristics except for the spring in the rainy season which was clear with tiny dark debris. The waters ranged from moderately acidic to weakly basic, having low mineral content and little dissolved solids. All major ions were within the WHO acceptable limits, thus suggesting no health risk to consumers. However, the spring source in the dry season and well in both seasons were hard, The waters were $Ca^{2+}-Mg^{2+}-Cl^{-}-SO_4^{2-}$ type in both seasons, which are typical of ground water. The waters were also acceptable based on water quality indices, the exception being the well which had poor quality in the wet season. Concerning the bacteriological quality, all samples had very high contents of faecal coliforms and pathogenic bacteria that justified the bad quality of these sources. This could be associated to poor hygiene and sanitation as well as poor source management and farming activities. The population is thus, exposed to water-borne diseases such as typhoid, diarrhoea and dysentery. On a general view, the water samples presented little or no health risk as far as organoleptic and physicochemical parameters were concerned. The great worry came from bad bacteriological quality with values above the WHO recommended limit (00 CFU/mL) for drinking water. Thus, home treatment of water such as chlorination, filtration, or boiling is required before consumption.

Data Availability

Relevant data are available for consultation if needed.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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