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Bacteriological and Physicochemical Quality of Groundwater of Mbankomo Municipality (Center Region, Cameroon)

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Abstract: A study to evaluate the physico-chemical and bacteriological quality of groundwater was carried out in the commune of Mbankomo (Centre-Cameroon) at 4 wells and 4 springs during the period from March to August. The physico-chemical parameters were measured by the standard method. Indicator bacteria of fecal contamination, namely HAB (Heterotrophic Aerobic Bacteria), total and faecal coliforms (*Escherichia coli*), and faecal streptococci were isolated by the surface spreading technique on PCA (Plate Count Agar), Endo and BEA (Bile Esculin Azide) agar respectively, and sulphite-reducing clostridia by the incorporation method on Tryptone Sulfite Cycloserine (TSC) agar. From a physico-chemical point of view, the groundwater in Mbamkomo is characterized by an average temperature (24.24 ± 0.24 °C); it is polluted with organic matter, acid and poorly mineralized. It was noted from a bacteriological point of view that these waters have a high and varied bacterial load with an average value of 100.8 x 10^5 CFU/100 mL for coliforms, 16.3 x 10^5 CFU/100 mL for fecal streptococci, 5.6 x 10^5 CFU/100 mL for *Escherichia coli* and 4.8 x 10^2 CFU/100 mL for *Clostridium perfringens*. These concentrations are all higher than the WHO (World Health Organization) standards which are set at 0 CFU/100 mL for coliforms, fecal streptococci and *Clostridium perfringens* and indicate fecal pollution of these waters. *Escherichia coli* cell densities were significantly correlated with dissolved oxygen in the water (r = 0.510; p < 0.05). The degradation of the quality of these waters is favored by their proximity to pollution sources, poor maintenance and poor protection of the wells. These waters, without any treatment, are not recommended for human consumption according to the standards of the WHO.

Key words: Groundwater, physico-chemical quality, bacteriological quality.

1. Introduction

Drinking water is a natural resource essential for life in any ecosystem [1]. Access to and maintenance of its quality is a major concern for a society that has to meet increasing water needs [2].

The water used for food is fresh water. It accounts for about 0.6% of the world's water, or 8 million km³, in rivers, lakes and groundwater. Its availability and quality are threatened by deforestation, climate change, population growth and intensive land use, particularly

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for agriculture and industry [3,4]. Its quality must be guaranteed in physical-chemical and microbiological perspective.

In Cameroon, 86.2% of the large cities, which house the majority of the population, are equipped with drinking water supply systems [5]. However, barely 25% of households actually have continuous access. Access to drinking water in urban areas is therefore selective, and populations located on the outskirts of cities have little access to it. They must therefore develop ways and means of coping with this shortage and for this purpose have recourse to groundwater such as wells and springs.

In many parts of the world, groundwater is one of the major sources of drinking water [6]. This resource is derived from vertical and horizontal infiltration of runoff and surface water. Groundwater is mostly exposed to biological and/or chemical pollution risks depending on the nature of the geological layers that separate the water table from the soil surface. They can harbour viruses, fungi, protozoa, insects and bacteria. These bacteria can be spherical, curved or rod-shaped. In addition, they may or may not be capped and may or may not have flagella [7]. The use of these waters is not always better in view of the numerous diseases such as gastro-enteritis, cholera and urinary tract infections that lead to deaths among the population every year. These diseases are closely linked to poor sanitation and lack of drinking water [8, 9]. Some studies have been carried out on the bacteriological quality of groundwater in Cameroon, particularly in Bafoussam locality, where the water has a relatively high and diverse bacterial load. The degradation of the water is due to the presence of latrines, rubbish heaps, farms, and the emptying of sewage works into the environment [10]. It has also been reported that well water from other localities in Cameroon, particularly Yaoundé, has nitrate values above 50 mg/L according to WHO standards and consumption of their water therefore exposes the young population to methaemoglobinaemia [9]. A study carried out on the evaluation of available water sources conducted in Mbankomo municipality showed that the populations of this locality obtain their drinking water from water points [11]. The above-mentioned study showed that the municipality of Mbankomo is not immune to problems of drinking water supply. This study evaluated the available water sources without assessing the quality of these waters. Furthermore, no information is available on the microflora of the groundwater and on the role that abiotic factors can play in the dynamics of the bacterial microflora potentially present. The presence of germs in drinking water can, however, be the cause of short-term health risks for people who consume this water. The present work aimed to evaluate the physico-chemical and bacteriological quality of water from some wells and springs in the municipality of Mbankomo. More specifically, the aim will be to isolate and enumerate the pollution indicator germs, which include HAB (Hydrophilic Aerobic Bacteria), total coliforms, faecal coliforms, faecal streptococci, *Escherichia coli* and sulphite-reducing clostridia or spores (*Clostridium perfringens*) and determine the importance of some abiotic variables on the distribution of these bacterial species.

2. Material and Methods

2.1 Description of Study Area and Sampling Stations

The area chosen for this study is located in the commune of Mbankomo. It is a commune of Cameroon located in the Center region, Department of Mefou and Akono, crossed by the National Road 3, 22 km from Yaounde and 28 km from Ngoumou, covering an area of 1,300 km². It lies between 11°13′ and 11°39′ East longitude and between 3°37′30″ and 3°52′ North latitude. The commune had 56,581 inhabitants, divided into 66 villages, of which 2 are in the urban area (Mbalngong and Mbankomo town) and 64 in the rural area. The hydrographic network is dense and made up of numerous water rivers. Fishing is practised in these rivers, especially during low-water periods, and sand is collected by hand. Fish farming is also practiced. The wells and springs were selected taking into account several criteria: the consent of the population, accessibility, distance between wells and also between springs, the existence of anthropogenic activities as well as their location in relation to the different sources of pollution (sewage and domestic solid waste spreading and inflow of industrial effluents with permanent flow) and the level of protection of wells.

Based on these characteristics, eight (8) sampling stations coded W_1, W_2, W_3 and W_4 for wells and Sp_1, Sp_2, Sp_3 and Sp_4 for spring water were selected in three villages of the municipality of Mbankomo (Mbankomo town, Nomayos and Binguela). Table 1 summarises characteristics of the wells and springs studies with geographical coordinates obtained in the field using a Garmin GPS (Global Positioning System) map 60CSX.

2.2 Measurement of Hydrological and Morphometric Characteristics and Environmental Variables

The height of the curbstone and the piezometric level were measured with a graduated string for the wells. Physico-chemical parameters are important for assessing the quality of drinking water as they impact on consumer health and influence bacterial pollution of drinking water. The selected parameters are temperature, pH, electrical conductivity, total dissolved solids, ammonium ions, nitrates, water color, suspended solids, dissolved oxygen, phosphates and dissolved CO_2. These are the parameters that are easily measurable and useful to see the evolution of the most dominant chemical elements in the well and spring waters of the study area, their concentrations and their origins. Samples for physicochemical analysis were collected in 1,000 mL clean polyethylene and were transported to the laboratory in a cooler with icepacks (7 ± 2 °C) for analysis. The analysis of these parameters was carried out according to the recommendations of APHA and Rodier and described by some of the authors [12-14].

2.3 Bacteriological Analysis

Bacteriological analysis can reveal faecal pollution of the water [15]. The bacteriological analyses consisted of the isolation and enumeration of HAB, total and faecal coliforms, faecal streptococci, *Clostridium perfringens* species and the identification of *Escherichia coli*. Indeed, 100 µL of the sample was taken with a sterile micropipette and deposited on the surface of the agar cast in Petri dishes. The sample was then spread on the culture medium, using a sterile until drying [16]. The culture media used were, the PCA (Plate Count Agar) for HAB. The spread was followed by an incubation at the temperature of the laboratory for 5 days. Endo culture medium was used for the isolation of *Escherichia coli*, total and faecal coliforms, incubated at the temperature of 37 °C and

Table 1 Characteristics of the wells and springs studies.

Sampling stations	Altitude (m)	Latitude	Longitude	Localisation/description	Main activities
W_1	750	N03°45′08.7″	E011°24′12.8″	At Binguela Station, presence of a cocoa field downstream from the source and an abandoned pond 2 m away	Drinking water, domestic use, bathing and crop irrigation
W_2	749	N03°47′01.4″	E011°24′14.2″	Mbankomo town, near the toilets (1 m)	
W_3	732	N03°46′39.0″	E011°27′30.4″	Behind the cement unit (CIMENCAM)	
W_4	745	N03°46′55.0″	E011°27′25.2″		
Sp_1	715	N03°41′47.3″	E011°22′49.7″	At the farming practical school in Binguela	-
Sp_2	722	N03°45′04.9″	E011°24′22.3″	At Binguela Station	-
Sp_3	741	N03°47′17.6″	E011°23′53.2″	Not far from the large waste dump (Mbankomo)	Drinking and household purposes
Sp_4	766	N03°46′55.0″	E011°24′13.8″	Downstream of the waste dump (Mbankomo)	Washing and swimming

44 °C respectively for 24-48 h; while faecal streptococci was seeded in BEA (Bile Esculin Azide) Agar at the temperature of 37 °C for 24 h. Tryptone sulfite cycloserine agar with additional egg yolk emulsion was used for the isolation of *Clostridium perfringens*. The culture was done anaerobically. During the culture, 1 mL of sample was first placed in the bottom of an empty sterile petri dish, covered with the medium, mixed and allowed to solidify before adding another layer of the culture medium. The petri dishes are then incubated at the appropriate temperature (46 °C). Strains with multiple cultural traits were counted by the direct counting method [17]. The count of isolated germs was carried out using an OSI brand colony counter. Bacterial abundances are expressed in CFU (Colonial Forming Units) per 100 mL of water sample.

2.4 Data Analyses

Data recording and histograms were made using Microsoft Excel 2016. The results of the recorded biological and abiotic parameters were analyzed using SPSS 25.0 software. The correlations between the biological and abiotic variables were calculated using Spearman's "*r*" correlation test; in fact, they will allow us to observe the degree of linkage between the parameters studied.

3. Results and Discussion

3.1 Hydrological and Morphometric Characteristics of the Wells Studied

The hydrological parameters measured varied from one well to another. The piezometric level values obtained fluctuated between 17.37 and 21.23 m. The highest value was noted at W_3 and the lowest at W_2. The different rim heights varied between 0.25 and 0.70 m. The highest value was recorded in W_1. The lowest value was recorded in W_3 (Table 2).

3.2 Environmental Variables

Water temperature varied from one sampling point to another (21-28.2 °C) with an average of 24.24 ± 0.24 °C (Fig. 1A). The highest value was recorded at W_3 in March and the lowest value was recorded at Sp_1 in May. These variations are due to the climate, which is characterised by abundant rainfall favouring the development of dense vegetation.

An average pH value of 5.9 ± 0.14 was recorded in the waters analysed and these waters have a pH with an acidic tendency. The pH varied throughout the study period and reached a maximum of 7.59 at W_4 in April. The minimum value is 3.8 obtained in April at Sp_2 (Fig. 1B). The values indicate that the well and spring water in this locality is generally acidic. In general, the pH values show that 75% of our analysed samples have values lower than 7. According to the WHO (World Health Organization) standard, the pH of drinking water should be between 7 and 8.5 [18]. The values obtained are close to the results of some authors who obtained pH values between 4.3 and 5.6 in well water in Yaoundé [19]. These pH values could be due to the quality of the subsoil in Mbankomo. Indeed, the pH of natural waters is linked to the nature of the terrain crossed [20]. It could also be linked to the production of CO_2 in the surface layers of the soil under the action of biological activities [21]. Slightly acidic water is not dangerous for the health of consumers. However, a low pH may indicate the presence of a pollutant in the water or a high mineralizing activity of bacteria near the water table.

Table 2 Morphometric and hydrological parameters of the studied wells.

Morphometric and hydrological parameters studied	Wells studied			
	W_1	W_2	W_3	W_4
Piezometric level (m)	19.4	17.37	21.23	18.65
Height of the well's curbstone (m)	0.70	0.60	0.25	0.65

Referring to the WHO standards for drinking water, about 75% of the analysed waters are not recommended for human consumption; the acidification phenomenon tends to lead to the dissolution of heavy metals which are very harmful for human health.

Dissolved oxygen levels fluctuated between 0.7 and 4.7 mg/L. The maximum value was recorded at Sp_4 in July. The values are relatively lower in March, April and May than in the last three months. The minimum value was obtained at Sp_1 in May and a mean value of 2.0 ± 0.19 mg/L was recorded (Fig. 1C). During both study periods, dissolved oxygen values are low in all sampled water points and remain below the standard. However, it is noted that the values obtained during the rainy period are significantly higher than those obtained during the dry period. The low oxygen points could be related to polluted water seeping into the groundwater or could also be explained by the absence of water-atmosphere contact and the perpetual renewal of water [1]. Winter seems to improve the oxygen content of well and spring water somewhat by bringing well-oxygenated water to the water table and by the cold which inhibits bacterial proliferation and therefore minimises their oxygen consumption. Overall, dissolved CO_2 values ranged from 0 to 22.88 mg/L. The maximum values were recorded in March at Sp_3 and W_4. The minimum value was recorded in April at Sp_1. The values in March are relatively high and constant while the other values are relatively low in the points during the rest of the study and an average of 8.20 ± 0.86 mg/L was noted (Fig. 1D). TDS (Total Dissolved Solids) values recorded during the study period ranged from 5 to 160 mg/L. The springs recorded low values throughout the study compared to the wells (mainly W_1, W_3 and W_4). The highest value was recorded for W_1 in July and the lowest value was recorded for Sp_2 in April. However, a mean value of 49.27 ± 17.71 mg/L was recorded (Fig. 1E). Electrical conductivity values ranged from 14 to 360 µS/cm. Wells coded W_1, W_3 and W_4 have higher values compared to W_2 and springs which have relatively low and constant values. The lowest value was recorded at Sp_2 in March, April and August and the highest value at W_1 in August. A mean value of 98.43 ± 35.52 µS/cm was recorded (Fig. 1F). Overall, the electrical conductivity and TDS values recorded are low. The average values recorded are 49.3 mg/L and 98.4 µs/cm for TDS and electrical conductivity respectively. These different values obtained indicate that these waters are poorly mineralised. However, the high values observed in wells W_1, W_3 and W_4 indicate a more or less significant mineralization in these waters due to the presence of minerals resulting from the dissolution of rocks interacting with the water they pass through. Furthermore, the mineralisation of groundwater depends on several parameters including the mineralogical nature of the rocks passed through, the contact time with the minerals, the water circulation rate, the aquifer water renewal time and rainfall [22].

Suspended solids values fluctuated between 0 and 85 mg/L. The well and spring waters showed relatively low or no suspended solids. At W_3 the maximum value was obtained in May. The minimum value was recorded in some of the points monitored and in all months except March. The average value of suspended solids is 8.17 ± 8.73 mg/L (Fig. 2A). Suspended solids concentrations in well and spring water are generally higher than WHO standards. They reflect pollution by clays, silts, litter debris, etc., which would be due to rainwater runoff that carries debris of all kinds and deposits it in wells and springs when they are not developed (protected by a cover and a high coping for wells, for example). This is not without consequence, despite their low concentration, because suspended solids can constitute a vector for the absorption of toxic substances by the body [23]. According to the WHO, suspended solids should be absent from drinking water, and for dishwater and laundry water, below 0.05 mg/L. The increase in TSS can be explained by the existence of agricultural land in these areas from which sanitary faecal products can infiltrate, by human activities and the presence of animals around the wells [18]. Water color values ranged from 0 to 374 Pt.Co with an average

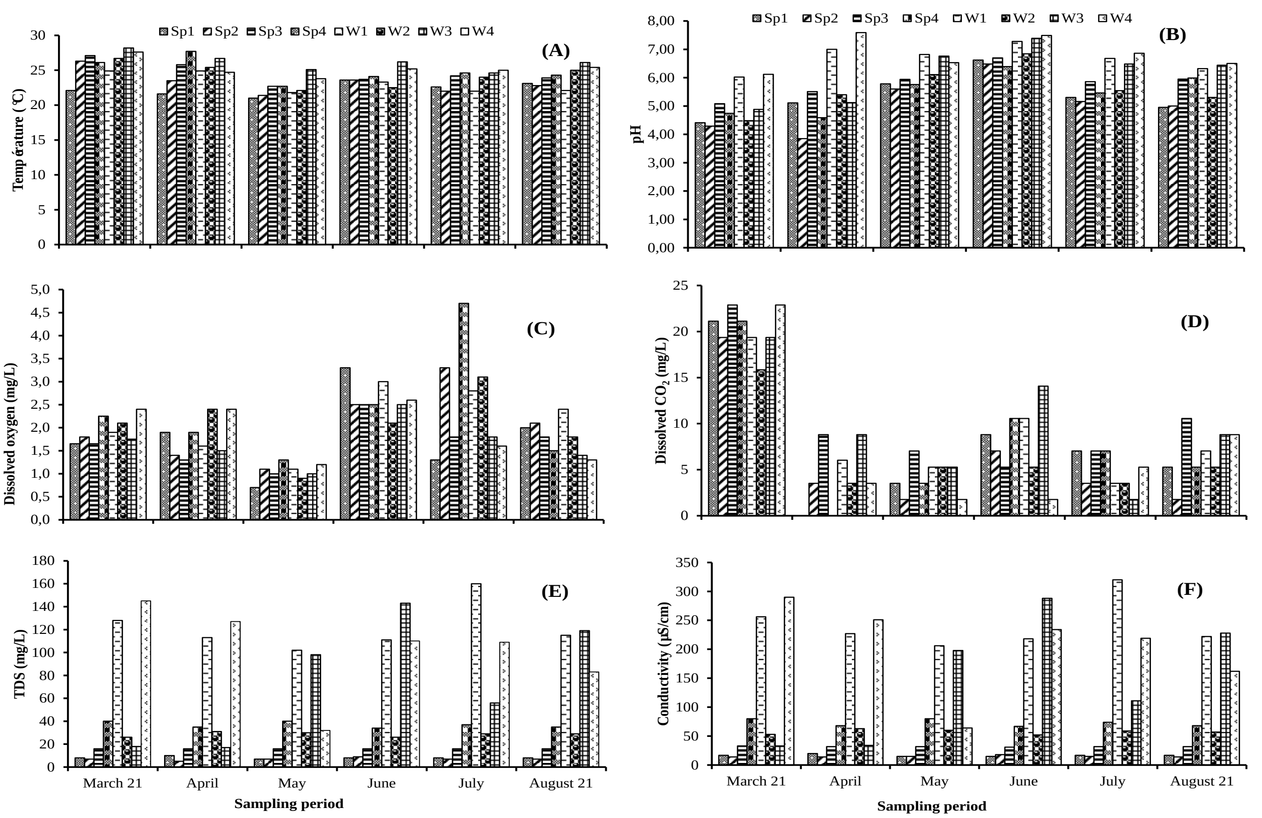

Fig. 1 Spatio-temporal variations of water temperature (A); pH (B); dissolved oxygen (C); dissolved CO_2 (D); total dissolved solids (E) and electrical conductivity (F).

value of 50.67 ± 43.24 Pt.Co. During the months of March, April and May, the values of water color are high compared to the last 3 months. The lowest value was especially marked in June at Sp_2, Sp_3, Sp_4, W_1 and W_2. But it is also present in July and August at Sp_1, Sp_2 and Sp_3. The maximum value was noted at W_3 in May (Fig. 2B). During the study period, nitrate values ranged from 0 to 116 mg/L NO_3^-. The nitrate content is low in all springs and in the majority of wells, except for W_2 and W_3 which have respective values of 116 and 55 mg/L of NO_3^- in the month of April. The lowest value was obtained in the month of May at W_3 and W_4 and in June at Sp_1, Sp_2, W_1 and W_4. The average is 9.48 ± 11.68 mg/L of NO_3^- (Fig. 2C). Ammonium ions values were low throughout the study, except for the month of May when high values were noted mainly at Sp_4 with a value of 1.7 mg/L NH_4^+. The minimum value of 0 mg/L of NH_4^+ was noted at points Sp_1 and Sp_2 in August and at Sp_4 in June (Fig. 2D). A mean value of 0.15 ± 0.06 mg/L of NH_4^+ was noted. The urban insalubrity that characterises the wells and springs enriches the water in ammonium and nitrates. These include points W_2; Sp_1, Sp_4 and W_3 respectively in April and May with ammonium ions values above 0.5 mg/L and wells W_2 and W_3 with nitrate values above 50 mg/L [18]. These increases in concentration are thought to be linked to the infiltration of wastewater or the use of chemical fertilisers in the vicinity of these wells [24]. Also, the presence of household waste dumps, livestock near the wells and the inadequacy of protection systems would contribute to the contamination of the water table with nitrogenous compounds [25]. In fact, from a sanitary point of view, well W_3 does not have a protective coping and there are toilets 1 m away and crops near well W_4. The pollution at the level of springs Sp_3 and Sp_4 most probably originates from the insufficiency of a system of collection, evacuation and treatment of household waste, and even less from that of collection, treatment and evacuation of wastewater. All these practices are sources of enrichment and contamination of groundwater by nitrates and ammonium ions. These excessively high concentrations are dangerous for the health of consumers, as they can cause methaemoglobinaemia in children, cancers in adults [26]. Throughout the study period, phosphate values ranged from 0.12 to 5.52 mg/L PO_4^{3-}. The maximum value was recorded at W_4 in the month of June. The minimum value was noted at point Sp_4 and W_1 in the months of July and April respectively (Fig. 2E). A mean value of 1.36 ± 0.49 mg/L of PO_4^{3-} was recorded. The average high phosphate content of around 1.37 mg/L could be due to the effect of human pollution (domestic waste, wastewater), to the nature of the land crossed, to the leaching of cultivated soils where fertilisers are used for fertilisation (the most frequent case) and in particular in connection with the discharge of detergents with which phosphates are frequently associated. Salinity values vary between 0 and 0.01 ppm. The values are zero in all points except in W_1 where the maximum value was recorded throughout the study. This value was also recorded at W_3 in the months of June and August and at W_4 in the months of March, April, June and July (Fig. 2F).

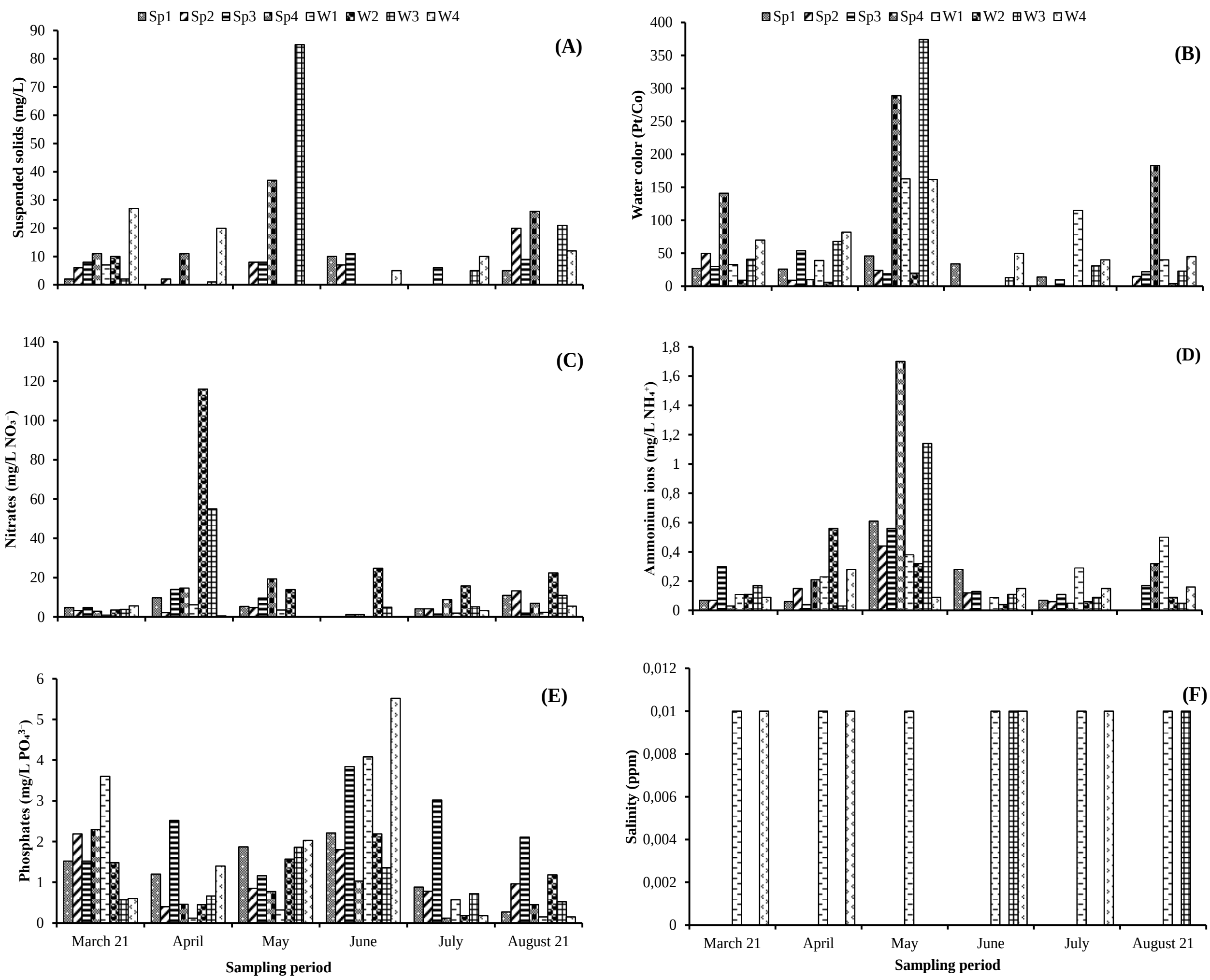

Fig. 2 Spatio-temporal variations of suspended solids (A); water color (B); nitrates (C); ammonium ions (D); phosphates (E) and salinity (F).

3.3 Bacteriological Characteristics

3.3.1 Macroscopic Examination of Isolated Bacteria

Macroscopic examination of the bacterial colonies on the different culture media revealed colonies of various colours and sizes. On ordinary agar medium, the HAB were whitish colonies of various shapes, sizes and appearances. For total coliform colonies, they are pink, small in size and those of faecal coliforms isolated on ENDO medium are dark red and metallic (presumptive *Escherichia coli* colonies). Faecal Streptococci were small translucent black halo colonies Bile esculin azide agar. On Tryptone sulfite cycloserine agar with additional egg yolk emulsion, *Clostridium perfringens* colonies are surrounded by a black halo, due to the reduction of sulphite to an iron sulphide precipitate.

3.3.2 Quantitative Distribution of Isolated Bacteria

The set of indicator bacteria for faecal contamination (HAB, total coliforms, faecal coliforms mainly *Escherichia coli*, faecal streptococci and *Clostridium perfringens*) varied throughout the study, from one sampling site to another and from one month to another. HAB were most abundant at all stations throughout the study period. The abundances of HAB cells fluctuated between 14 and 4.7 $\times 10^5$ CFU/100 mL. The lowest value was obtained at Sp_3 during the month of April and the highest value in March at Sp_1 (Fig. 3A). The HAB include all the microorganisms representing the bacterial flora. The results obtained show that the majority of the wells and springs monitored contain HAB in their water, with values that are all higher than the WHO standards, with 100 CFU/100 mL [18]. The contamination of these waters by total germs could be due to the poor protection of the wells (open wells) and springs, the lack of knowledge of basic hygiene rules, the surrounding pollution (existence of septic tanks and latrines) and the absence of a sanitation network. The density of total coliforms varied from 0 to 1.2 $\times 10^5$ CFU/100 mL. The minimum value of 0 was recorded in May in Sp_1 and Sp_2 as well as in W_1, W_2, W_3 and W_4. The maximum value of 1.5 $\times 10^5$ CFU/100 mL was recorded in March at Sp_4 (Fig. 3B). It can be seen that the months of March, April and August show higher values than the months of May, June and July. The abundances of faecal coliforms fluctuated from 0 to 146 $\times 10^5$ CFU/100 mL during all the campaigns. The lowest value of 0 was observed in May in springs Sp_1, Sp_2 and wells W_1, W_2, W_3 and W_4 and the highest value of 146 $\times 1\ 0^5$ CFU/100 mL in August in Sp_4 (Fig. 3C). Total coliforms are of animal and human origin, their presence in the water indicates recent contamination by faecal matter. The results of total coliforms show that they are most abundant in the samples during the months of March, April and August and these values are all above the WHO standards which are set at 0 CFU/100 mL [18]. The high bacterial load can be caused by domestic discharges and by surface water infiltration into wells. These causes are similar to those detected in the some studies conducted on the pollution of well water in some districts of the city of Fez in Morocco [27]. Fecal coliforms, whose presence in water indicates fecal pollution of animal or human origin, demonstrate the potential presence of pathogenic organisms capable of causing enteric diseases. There is a decrease in the number of faecal coliforms during the wet season in most of the wells and springs in the study, due to a strong dilution of coliforms caused by groundwater recharge. During the dry and rainy periods, only the Sp_4 has a very high peak of faecal coliforms and *Escherichia coli*, this would be due to the state of insalubrity observed, from the unauthorised rubbish dumps and septic tanks a few metres from the Sp_4. These are all parameters that would explain not only the high density of bacterial populations recorded, but also their great diversity. In fact, hygiene and sanitation are among the main factors that favour the pollution of water sources. It is therefore important to analyse household practices in this regard. The density of faecal streptococci fluctuated between 0 and 381 $\times 10^5$ CFU/100 mL throughout the campaigns. The minimum value was noted in all months except

March. It was recorded in April in Sp_2, W_2 and W_3; in May in Sp_1, Sp_2, Sp_3, W_1, W_2 and W_3; in June in Sp_2, Sp_4 and W_2; in July in Sp_2 and W_3 and finally in August in points Sp_1, Sp_2, Sp_3, W_1 and W_2. The maximum value was recorded in August at source Sp_4 (Fig. 3D). Throughout the study, fairly high concentrations of faecal streptococci were recorded in the well and spring waters analysed. This number of faecal streptococci far exceeds the WHO standards, which are set at 0 CFU/100 mL [28]. The presence of large numbers of faecal streptococci in well and spring water attests to the contamination of the water by faecal matter stored in latrines (average distance = 8 m); and suggests the presence of enteropathogenic micro-organisms [29].

The abundances of *Clostridium perfringens* cells ranged from 0 to 35×10^2 CFU/100 mL. The minimum value of 0 CFU was observed in the last two months, as well as in March and June, at Sp_1, Sp_2, Sp_3, W_1, W_2, W_3 and Sp_1, Sp_2, W_2 respectively. The highest value was noted in May at Sp_3 (Fig. 4A). The abundances of

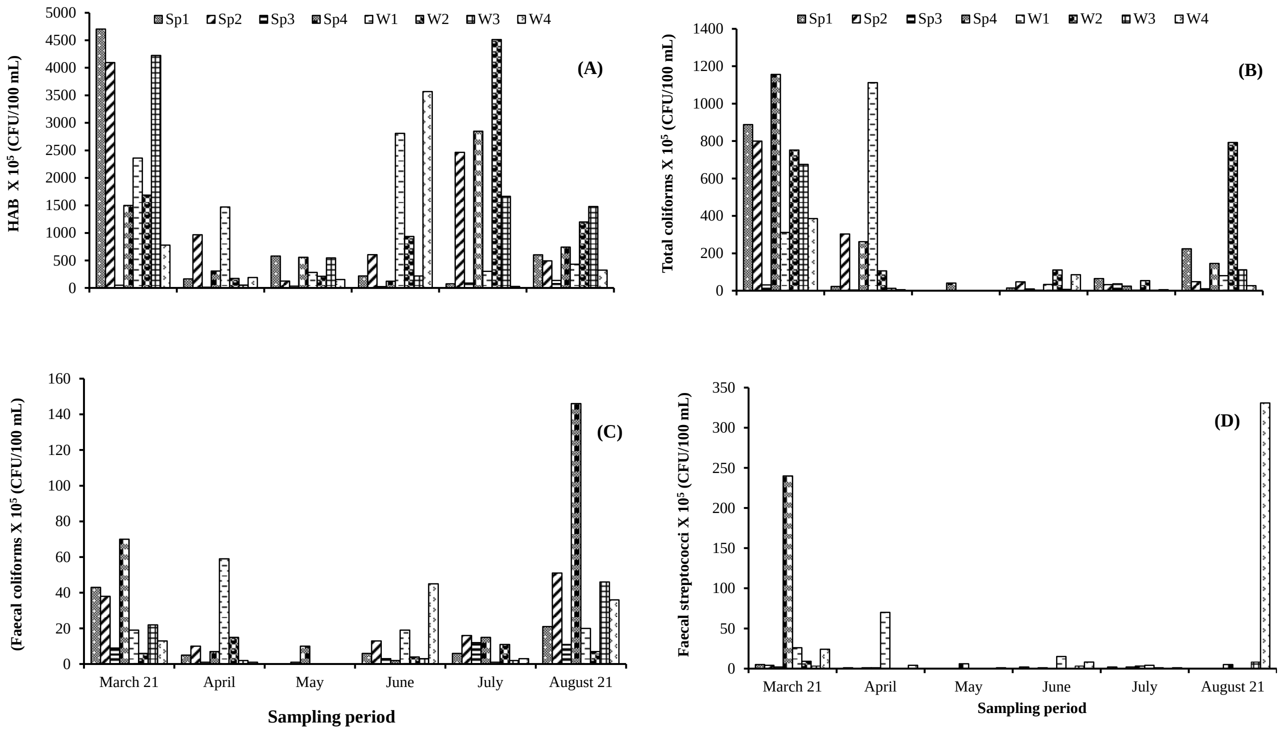

Fig. 3 Spatio-temporal variations in cell abundance of: Herotrophic Aerobic Bacteria (A), Total Coliforms (B), Faecal Coliformes (C) and Faecal Streptococci (D).

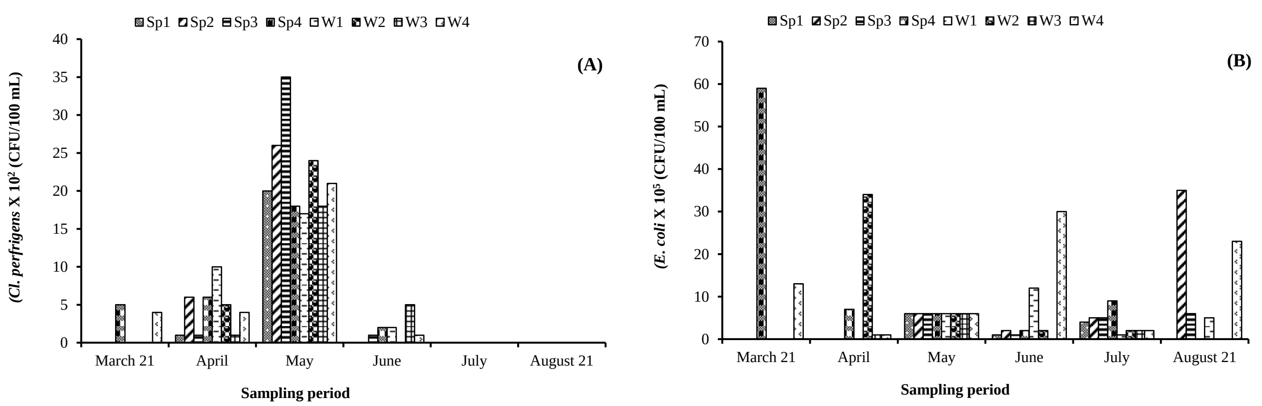

Fig. 4 Spatio-temporal variations in cell abundance of *Clostridium perfrigens* (A) and *Escherichia coli* (B).

Escherichia coli cells fluctuated between 0 and 59 × 10^5 CFU/100 mL. The maximum value was recorded at Sp_4 in March. The minimum value was recorded in April at Sp4, W_2, W_3 and W_4; in June at W_3; in August at points Sp1, Sp4, W_2 and W_3. This value was also present in all points except Sp_4 and W_4 in March and Sp_4 in May (Fig. 4B). *Clostridium perfringens* is a bacterium that can sporulate and remain in water for a long time. It is therefore a witness of old pollution. It is more difficult to kill than coliforms by disinfectants and is therefore a good indicator of the effectiveness of disinfection [30]. Their abundance was highest during the month of May in all samples, but it is also present in spring and well water during the months of March, April and June. The obtained values during this study do not comply with WHO standards which recommend a maximum number of *Clostridium perfringens* at 0 CFU/100 mL of water sample [18]. Indeed, the presence of sulphite-reducing anaerobic spores in natural water suggests faecal contamination and, in the absence of coliform bacteria, old contamination [31]. They are very persistent and their presence is a good indicator of aquifer and well vulnerability [32]. The microbiological quality of these waters shows that they are unfit for consumption before treatment as their values are all above the standards established by the WHO. Similar results were obtained in Douala (Cameroon) and Ngaoundéré (Cameroon) respectively, who revealed faecal contamination by the individual or combined presence of total coliforms, thermotolerant coliforms, faecal Enterococci and *Clostridium perfringens* in well water [6, 23].

Dissolved oxygen content was significantly positively correlated with *Escherichia coli* species and negatively correlated with *Clostridium perfringens* species. Dissolved carbon dioxide, TDS and electrical conductivity were significantly positively correlated with faecal streptococci. Indeed, the influence of chemical compounds on the soil and subsoil microflora depends on the ability of the bacterial species to degrade this chemical compound, either to neutralise its toxicity or to make available the nutrients and energy source, which are necessary for its biosynthesis. Table 3 presents the correlations between physico-chemical parameters and bacterial abundances in spring waters. It can be seen that there are significant and negative correlations between HAB abundances and pH and between the bacterial species *Clostridium perfringens* and dissolved oxygen. Significant and positive correlations were recorded between faecal streptococcal abundances and parameters such as dissolved CO_2, TDS, electrical conductivity and between *Escherichia coli* species and parameters such as dissolved

Table 3 Correlations between physicochimical and bacteriological parameters for spring water.

Physicochimical parameters	Bacteriological parameters					
	HAB	Total coliforms	Faecal coliforms	Faecal streptococci	*Clostridium perfringens*	*Escherichia coli*
Temperature	-0.040	0.292	0.283	0.394	-0.234	0.242
pH	-0.472*	-0.664**	-0.387	-0.170	0.024	0.056
Dissolved oxygen	0.277	0.156	0.384	0.014	-0.476*	0.511*
Dissolved CO_2	-0.014	0.207	0.177	0.407*	-0.308	0.055
TDS	-0.185	-0.008	0.071	0.495*	0.123	0.415*
Conductivity	-0.177	-0.021	0.046	0.456*	0.159	0.368
Suspended solids	-0.055	-0.117	0.180	0.101	-0.163	0.209
Color	0.042	0.077	0.041	0.560**	0.178	-0.228
Nitrates	0.006	0.050	-0.009	0.086	0.265	-0.063
Phosphates	-0.360	-0.224	-0.189	0.143	-0.063	-0.033
Ammonium ions	-0.179	-0.288	-0.371	0.049	0.397	-0.269

** Significant correlation at level 0.01; * Significant correlation at level 0.05.

Table 4 Correlations between physicochimical and bacteriological parameters for well water.

Physicochimical parameters	Bacteriological parameters					
	HAB	Total coliforms	Faecal coliforms	Faecal streptococci	*Clostridium perfringens*	*Escherichia coli*
Temperature	0.112	0.481*	0.384	0.316	-0.119	-0.001
pH	-0.165	-0.367	-0.090	0.198	0.325	0.156
Dissolved oxygen	0.358	0.299	0.293	0.245	-0.313	0.510*
Dissolved CO_2	0.224	-0.499*	0.393	0.446*	-0.173	-0.212
TDS	-0.062	-0.076	0.137	0.484*	0.105	0.082
Conductivity	-0.067	-0.090	0.128	0.497*	0.122	0.111
Suspended solids	-0.119	0.062	0.109	0.297	0.040	-0.176
Color	-0.381	-0.459*	-0.349	0.037	0.337	-0.116
Nitrates	-0.089	0.345	0.146	-0.298	-0.142	0.65
Salinity	0.000	0.054	0.248	0.452*	0.045	0.070
Phosphates	0.180	-0.117	-0.270	-0.001	0.206	-0.131
Ammonium ions	-0.267	-0.274	-0.138	-0.117	0.365	-0.031

* Significant correlation at level 0.05.

oxygen and TDS. A highly significant and negative correlation was noted between total coliforms and pH and a highly significant and positive correlation was also noted between faecal streptococci and water color.

In the studied well waters, significant negative on the one hand and positive correlations on the other hand were recorded (Table 4). The first type was noted between total coliforms and parameters such as dissolved CO_2 and water color. The second type was recorded between total coliforms and temperature, and between faecal streptococci and variables such as dissolved CO_2, TDS, electrical conductivity and salinity; and finally between the bacterial species *Escherichia coli* and dissolved oxygen.

4. Conclusion

The well and spring waters analysed are polluted with organic matter, acidic, poorly mineralised and subject to moderate pollution. The physico-chemical quality of these waters does not pose any major health problems. Bacteriological analyses revealed the presence of fecal pollution indicator germs in high proportions that are not recommended for drinking water and led to the conclusion that the water analysed was bacteriologically polluted. These bacteria are responsible for bacterial diseases such as gastro-enteritis, typhoid fever, cholera and dysentery in humans. Parameters such as temperature, pH, dissolved oxygen, dissolved CO_2, TDS, electrical conductivity and salinity significantly influenced the distribution of bacteria.

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