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Evaluation of Quality Borehole Water Consumed in Public Schools in N'Djamena City (Chad)

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Abstract: In N'Djamena city, majority of population living there is connected to drinking water supply network. However, given untimely water cuts, some schools have chosen to carry out private drilling. Our objective is therefore to assess the quality of water intended for human consumption in these schools, to do this we have carried out a physico-chemical and bacteriological control on a number of water points. Seventeen (17) water points were collected during July 2015 and the physico-chemical parameters analyzed are as follows: pH, EC (Electrical Conductivity), TH (Total Hardness), turbidity, Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, NO_3^-, HCO_3^- and SO_4^{2-}. In addition to this, we looked for possible undesirable germs, indicators of pollution. The results of physico-chemical analyses carried out show that water from most boreholes has good quality with the exception of drilling F7, which has a high conductivity, and drilling F3 whose turbidity is also high. Bacteriological analysis shows that all water points contain total germs, the other germs of faecal origin are mainly present in the F9 borehole.

Key words: Drilling, physico-chemistry, bacteriology, quality, N'Djamena.

1. Introduction

Water is an indispensable resource for basic needs of man and his environment, but it is enormously threatened in semi-arid and arid areas. Periods of drought, which have severely affected many regions in sub-Saharan Africa, have highlighted the precariousness of groundwater and surface water reserves in these areas, leading to an increased decrease in the quantities of water available. To this anthropogenic constraints that affect more and more its potability are added. By definition, water intended for human consumption is drinkable when it is free of chemical and biological elements that may affect the health of individuals in the more or less long term [1]. Groundwater, which meets this criterion, is generally an excellent source of drinking water supply. This is why the populations for their consumption increasingly solicit them. Indeed, it is estimated that about 75%-90% of world's population consumes groundwater [2, 3]. In developing countries, obtaining safe water for human consumption has become a serious problem due to the lack of environmental protection [4]. And if adequate measures are not taken quickly by our leaders, these countries are heading towards a freshwater crisis because of the mismanagement of water resources and environmental degradation. It should be noted that water chemistry is very dynamic; indeed, the chemical composition of water changes even more quickly when it is in contact with certain minerals such as carbonates and evaporites because the latter dissolves quite quickly. This change is less rapid in case of contact with other minerals, such as silicates, because they dissolve more slowly and therefore have less effect on the chemical composition of the water.

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Regarding its quality, it is the result of a natural acquisition of mineralization to which anthropogenic inputs are added contributing to their pollution [5, 6]. Naturally the quality of the water is influenced by a number of factors such as climate, chemical composition of infiltration water, residence time, geology of the reservoir rock among others. However, it can be altered when it is brought into contact with certain elements such as pathogenic microorganisms or even toxic substances that can make it unsuitable for domestic consumption [7]. And this can have adverse health effects [8] thus water that is a source of life can become a source of diseases and for the need of public health it is essential to identify the chemical quality of groundwater. A number of previous works [10-12] report on groundwater degradation in N'Djamena city, this degradation is mainly related to the influence of anthropogenic activities. It is therefore imperative to regularly monitor the quality of groundwater intended for consumption and to find the right ways to protect it in the event of a problem. The main state water distribution company, the STE (Chadian Water Company) is facing many water supply problems in the city and this is accompanied by untimely cuts. This is why many public schools prefer to carry out private drilling (manual pump) to ensure their autonomy in terms of drinking water supply.

2. Materials and Methods

2.1 Presentation of the Study Area

2.1.1 General and Demographic Framework

The N'Djamena city is located in western Chad at 15°2′ East longitude and 12°7′ North latitude, and is at an altitude varying between 294 and 298 m (Fig. 1). It is located on a relatively flat area with an average altitude varying between 280 and 320 m (Fig. 1) and has relatively low natural slopes varying between 1% and 2.5%; it now covers an urbanized area of about 41,000 hectares, or 3.1% of the total area of Chad [13].

As in all cities of world, the population is constantly growing and is currently the order of 1500,000 inhabitants with an annual growth rate of about 7% and a density of about 83 inhabitants/ha according to the report of national symposium 2013. This population represents 8% of total population and 41% of country's urban dwellers. Administratively, Ndjamena city is divided into ten (10) administrative units called Municipal Districts and subdivided into 78 districts and 1,650 squares. The latter represents the smallest administrative entities in the city (Fig. 1). The city is part of the Lake Chad Basin which is the largest endorheic basin in the world (2,500,000 km^2). The average annual rainfall is of the order of 540 mm, such rainfall is characteristic of sahelo-Sudanian environments located between isohyetes 500 and 700 mm. In addition, our study area is marked by high interannual variability of rainfall, so on a 30-year rain chronicle (1984-2014), it was found that in 1998 and 2006, precipitation reached the respective maximum values of 775 and 711 mm corresponding to the wettest years. While for the years 1984 and 1990, values were noted minimum respectively 226 and 296 mm of rain representing the driest (deficit) years. The average temperature calculated over 10 years of observation from data from the ANAM (National Meteorological Agency) is about 28 °C, with a monthly minimum of 23.4 °C and a monthly maximum of 33.5 °C. Most of the hydrographic network of this area is composed of two main rivers: the Chari and its main tributary the Logone. These two rivers have their sources respectively in Mount Yadé in the Central African Republic, and on the Adamawa plateau in Cameroon. The Chari results from the junction of several rivers (the Bamingui, the Gribingui and the Bangoran) as for the Logone, it results from the convergence of two rivers: Vina and Mbéré. These two rivers meet in N'Djamena before reaching Lake Chad where they provide most of its food. The Logone/Chari river system accounts for about 90% of lake Chad's water [14]. Throughout

N'Djamena city, we note the presence of depressions that correspond to quarries dug for the construction of houses. During the rainy season, rainwater and runoff accumulate in these depressions giving rise to more or less permanent ponds depending on their importance. There is also the presence of a large canal that crosses the city from north to south and is intended to drain sewage. The groundwater table is fed mainly by the river and to a lesser extent by rain. The influence of surface water on the quality of groundwater under the city is also noted [10, 11, 15].

2.1.2 Geological and Hydrogeological Context

The study area represents a tiny part of one of the large post-Paleozoic African sedimentary basins which is the Lake Chad Basin, set up during the Upper Jurassic-Lower Cretaceous distension phase (150-120 Ma) and which is marked by the presence of a large ditch that opened as a result of deep subsidence of Precambrian basement. The filling of this basin began as early as the Late Cretaceous and continued until the Quaternary [16] and the deposits are essentially continental. Cores taken during oil and hydrogeological exploration and geophysical logs show that sediments are essentially made up of alternating sandy and clay series [17].

At the height of N'Djamena city, the depth of crystalline base could not be determined with precision because one of the largest boreholes, carried out in 1950 (356 m deep), did not allow reaching it; However, a depth of 550 m has been estimated thanks to seismic investigations [18]. The oldest sedimentary deposits that had to be preserved in basement depressions are not precisely known and the cutting carried out at the scale of the basin [19] highlights the non-existence of primary and secondary although some authors believe that the Cretaceous would be present in this area [18]. In general, the Continental Terminal rests directly on the base. Drilling carried out in the Chari-Baguirmi has made it possible to determine its thickness, which varies between 80 and 100 m. However just in front of N'Djamena on the other side of the Chari (Kousseri), the thickness of this the same formation has been estimated at about 200 m and corresponds to two successive sets [16]: 110 m of a clay-sandstone series, versicolor to gray with intercalations of three (3) levels of sand and about 100 m of a sandstone detritic series. The Pliocene, which surmounts the Continental Terminal, can reach several hundred meters in thickness. The deposits of the Lower Pliocene are essentially sandy while those of the Middle and Upper Pliocene are clayey with sandy intercalations.

Quaternary deposits with a thickness of about 50 m rest on all of these earlier formations. The lower limit of the Quaternary could not be precisely determined and it seems that it corresponds to the completion of the long clay sedimentation around 60 to 70 m depth in N'Djamena [16, 20]. The mode of sedimentation of the Quaternary is linked to an alternation of increase and reduction of the surfaces of the paleo Lake Chad, in connection with the humid-arid climatic fluctuations [20].

The cuts made to the west of the city in the Quaternary (Fig. 2) show an alternation of sands and clays as well as the presence of intermediate facies (sandy clay or clay sand). There is also a spatial variation in the thickness of the surface clay layers; these levels can have a decisive role on the existence or not of infiltration zone and therefore the recharge of the surface aquifer. The subsoil of the city of N'Djamena contains, as a whole, two superimposed aquifer levels [16, 18, 20, 21]. The lower limit of the upper water aquifer is represented by clay banks encountered in the 1967 brGM boreholes at a depth of about 19 m. The thicknesses of these clay banks are very variable. The lower limit of the second aquifer would be at a depth ranging from 60 to 75 m deep. The latter is separated by an impermeable to semi-permeable clay level in places; these two aquifers are rather part of the same whole, because it is the sandy sedimentation marked by the deposits of clay lenses which allowed their differentiation. In addition, the BRGM [22] also

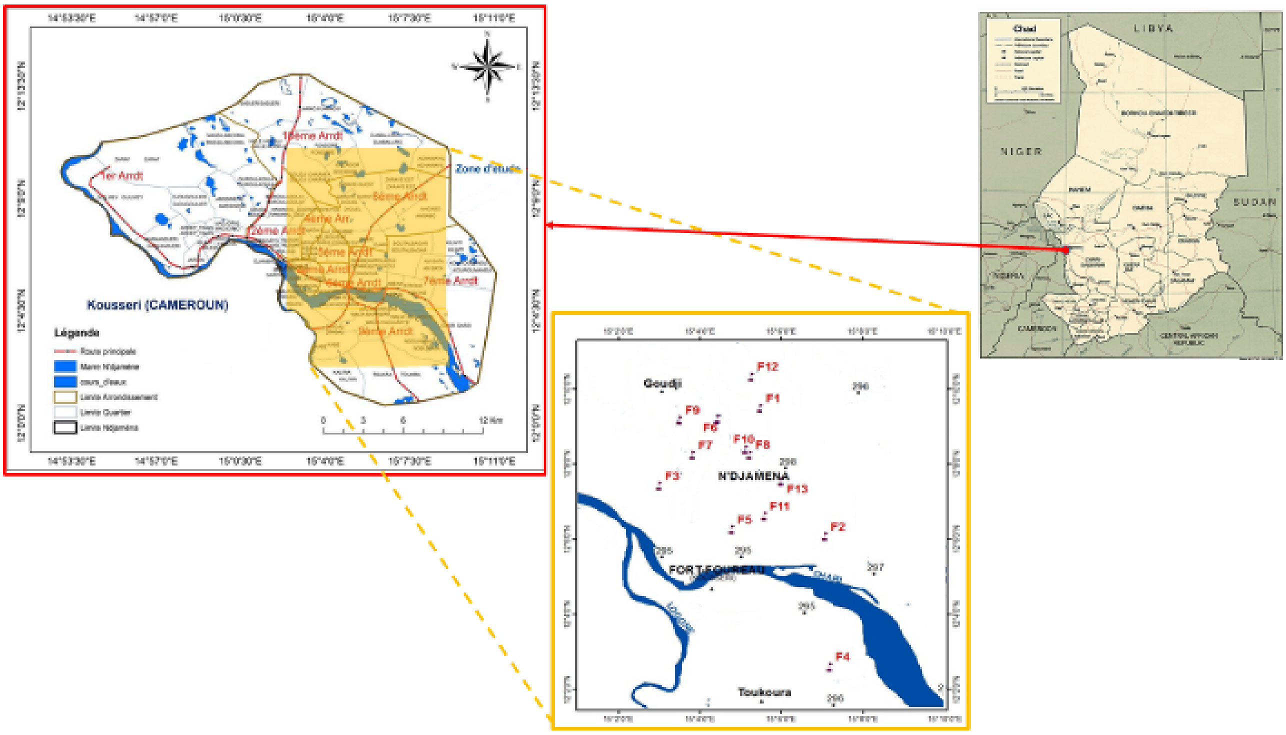

Fig. 1 Geographic location map of our study area and location of the points sampled as of July 2015.

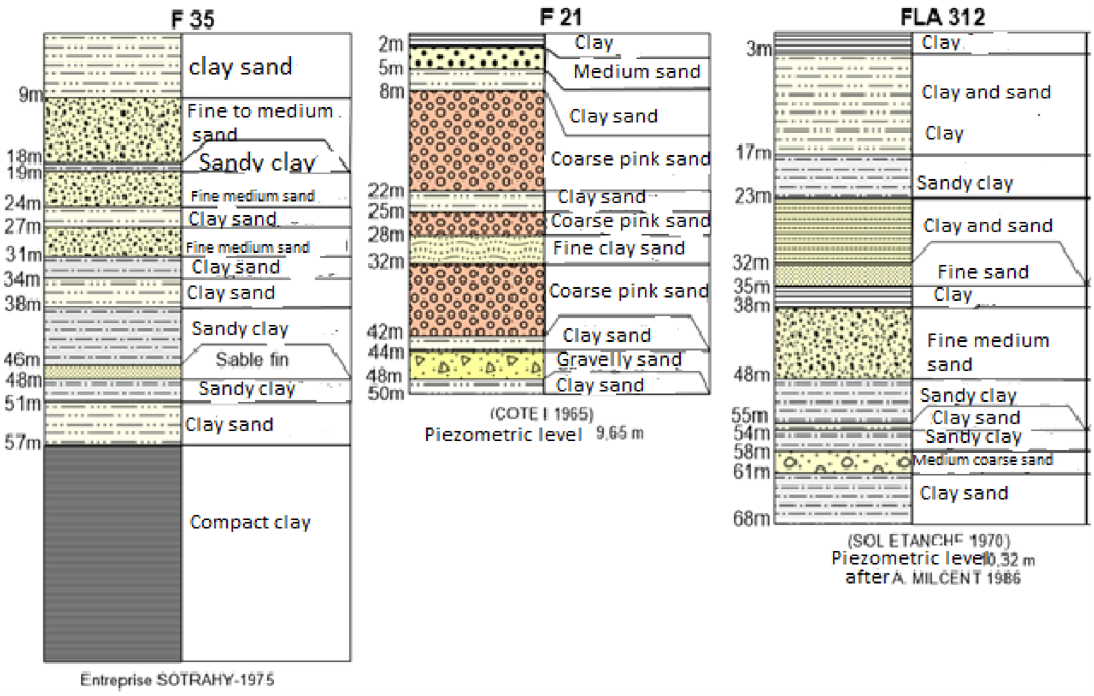

Fig. 2 Lithological section of boreholes west of N'Djamena city [20].

reports locally the presence of intermediate aquifers at a depth of 20 to 30 m. The Quaternary aquifer is therefore a multilayer aquifer. The surface slick is captured by the open wells while the underlying groundwater, concerned by this study, is captured by the hand pumps.

2.1.3 Data Collection and Analysis

This study is based on physico-chemical analyses of 13 water samples taken mainly from boreholes of schools distributed in N'Djamena city in July 2015. The sampled points were located using a Garmin-branded GPS (Global Positioning System). The pH was measured *in situ* using an mettle Toledo one brand pH meter, MMPS-T1 series and the conductivity thanks to the WTW-31 10 brand conductivity meter. Turbidity was measured with the HACH Lange 2100Q turbidimeter. Samples for chemical analysis are taken from polyethylene vials with a capacity of 1.5 L. The latter and their caps were thoroughly washed three times with the water to be taken. The filling of the cylinders was done to the brim and then the cap was screwed in to avoid any gas exchange with the atmosphere. The bottles were indelibly labelled (name, date and time of sampling), and then transported in a cooler to LNAE (National Laboratory of Water Analysis) of N'Djamena for analysis. HCO_3^-, Cl^-, Ca^{2+} and Mg^{2+} were determined by the volumetric method, NO_3^-, SO_4^{2-}, were determined using the DR2800 spectrophotometer and K^+, Na^+ were determined using the flame spectrophotometer.

For bacteriological parameters, water samples were collected in well-sterilized polyethylene vials to avoid accidental contamination and the analysis was carried out within a time interval not exceeding 48 h after sampling. The study of bacteriological parameters focused on the research and enumeration of germs indicative of pollution that are FAT (Total Aerobic Flora), T.C. (Total Coliforms), *Escherichia coli* (*E. coli*) and EF (*Fecal enterococci*). For the FAT, the water analyses were carried out by deep seeding in PCA (Plate Count Agar) agar (the glucosed agar with yeast extract called by the Anglo-Saxons "Plate Count Agar"). Enumeration of this germ was made after 48 h of incubation at 37 °C. Total coliforms, *Escherichia coli* (*E. coli*) and *Fecal enterococci* were determined by the filtration method.

The enumeration of total and faecal coliforms was carried out on Chromocult Agar and then incubated at 37 °C for 24 and 48 h respectively, for total coliforms and *Escherichia coli*. *Fecal enterococci* was counted on Slanetz & Barthley agar after incubation at 37 °C for 48 h. The result was expressed as CFU (Colony Forming Unit) per milliliter (mL) of water sample.

2.1.4 Validity Results and Data Processing

The validity of results of chemical analyses was checked by the calculation of ion balances. Overall, the results are acceptable because all samples of analyzed waters (i.e. 100%) have an ionic balance less than or equal to 5%.

The data processing from physico-chemical analyses was carried out by the hydrochemical approach using Simler's diagram software (2005), in order to determine the different hydrogeochemical facies of water collected. Data were also compared the WHO (World Health Organization) guide values (2011) for drinking water and the chemical composition of certain mineral waters sold in shops such as Cristalline and Excel bottled in Chad or Evian and Volvic imported from France (Table 1).

3. Outcomes and Discussions

3.1 Physico-Chemical Characterisation of Waters

3.1.1 Physico-Chemical Parameters

The various results of physico-chemical analyses carried out on groundwater collected at the various schools in N'Djamena city, those of mineral waters sold in shops and WHO guide values (2011) are presented in Table 1.

EC (in μS/cm) indicates ability of an aqueous solution to conduct electric current. It depends on presence of ions and their relative concentration. It is proportional to mineralization [23]; fresh water generally reflects a relatively low conductivity while it reflects a fairly high conductivity when it is said to be hard. In arid and semi-arid climates, often very high temperatures cause a significant evaporation of water. This results in a high concentration of salts in water which results in an increase in values of EC. The latter also varies according to the geological substrate crossed. In our case, EC is between 113 µS/cm for the Abena School (F2) and 1,546 µS/cm for the 4th Municipal School Rounding (F7) with an average of 438.54 µS/cm (Table 1). According to the classification of Potelon and Zysman [24], the ECs obtained in our water samples have low to medium degrees of mineralization, with exception of F7 which has a rather excessive mineralization (Fig. 3). However, these waters are all included in the range of conductivities allowed by the WHO (Table 1), with exception of drilling of the Communal School 4th Arrondissement (F7).

The pH of natural waters is an important parameter which allows to define the aggressive or incrusting character of a water and conditions many physico-chemical balances. Like EC, it also varies according to nature of soils crossed, it can also be influenced by various natural or anthropogenic activities [25]. pH values vary between 7.08 in the Communal School 4th Arrondissement (F7) and 7.87 (Drilling F5 of Belle-Vue School) with an average of 7.51 (Table 1). All of our waters have pH levels that meet WHO standards (6.5-8.5).

Turbidity is an organoleptic parameter and makes it possible to express the optical properties of a water to be absorbed and/or diffused by light. It is due to presence of finely divided suspended solids: clays, silts [26], as well as organic matter (dead organic matter or decaying plants, suspended plankton) and other microscopic matter that forms an obstacle to the passage of light through water [27, 28]. Turbidity varies between 0.00 NTU measured at Belle Vue School (F5) and 9.00 NTU measured at Bololo School (F3) with an average of 1.90. All turbidity values are below the WHO standard (Table 1), except for F3 drilling whose value exceeds the WHO standards (≤ 5 NTU). This borehole is located near Canal Saint Martin which evacuates wastewater to the Chari and would probably be under the influence of wastewater collected by this canal.

Table 1 Statistical results of different physico-chemical parameters of pre-emergence water in the different schools.

Parameter	Values of parameter in water withdrawn				Commercial mineral waters				OMS (2011)
	Min	Max	Moy	Ecart-type	Excel (Tchad)	Cristal (Tchad)	Volvic (France)	Evian (France)	
EC (µS/cm)	113	1,546	438.54	371.53					180-1,000
pH	7.08	7.87	7.51	0.25					6.5-8.5
Dissolved total solids (mg/L)	58	779	220.08	186.98					-
Turbidity (NTU) (mg/L)	0	9	1.9	2.27					5
TH ($CaCO_3$) (mg/L)	60	180	98	35					-
Ca^{2+} (mg/L)	19.2	54.4	28.95	10.75	9.05	18	9	78	200
Mg^{2+} (mg/L)	1.9	15	6.22	3.68	2.05	5	6	24	-
K^+ (mg/L)	1	7	3.08	1.66	1.7	3.9	6	4	12
Na^+ (mg/L)	16	38	22.35	5.47	16	17.2	5	6	
HCO_3^- (mg/L)	70.5	219.6	115.78	42.57	130	108	61	357	-
Cl^- (mg/L)	13	40	21.58	7.11	0.55	6	6	2	250
SO_4^{2-} (mg/L)	1.5	14	6.29	4.19	5	8.4	10	32	250
NO_3^- (mg/L)	1.3	28.1	7.35	7.65	trace	trace	4	5	50
Escherichia coli (UFC/100 mL)	0	8	0.62	2.22					0
Total coliforms (UFC/100 mL)	0	29	2.23	8.04					0
Fecal enterococcus (UFC/100 mL)	0	21	1.62	5.82					0
FAT (UFC/100 mL)	12	42	25.54	8.43					-

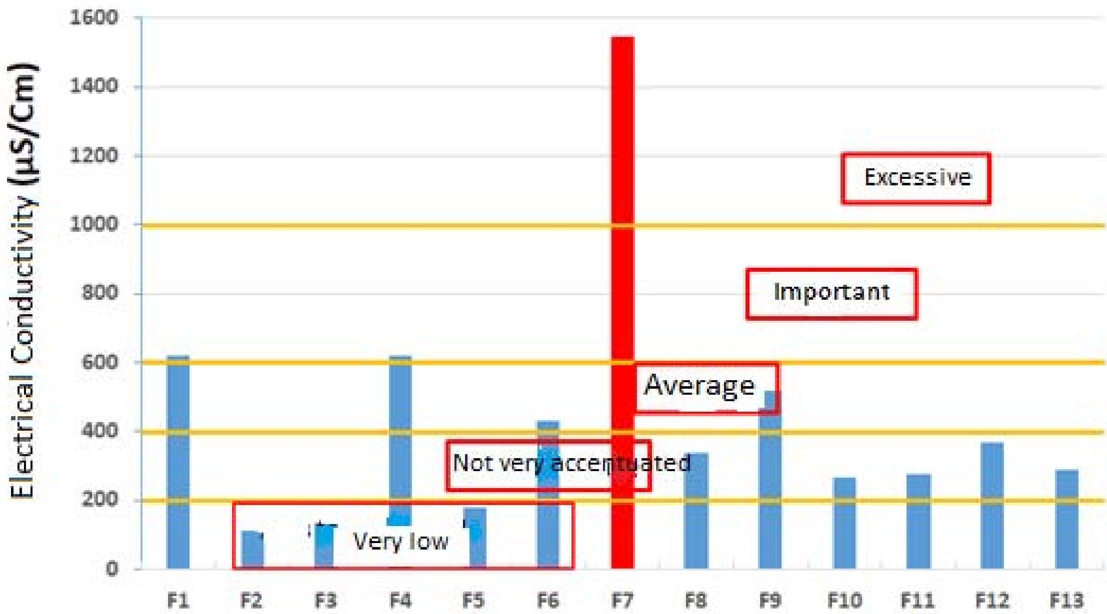

Fig. 3 Distribution of EC in boreholes.

TH (Total Hardness) is an important criterion for determining the relevance of water to domestic, drinking and industrial supply [29]. We differentiate the TH, which is mainly due to presence of cations such as calcium and magnesium, and carbonate hardness related to presence of anions such as carbonate and bicarbonate. Water containing excess hardness is not dangerous to health; however it is not desirable for drinking water. This type of water forms scales on the water heater and utensils when used for cooking, in addition, it consumes more soap when washing clothes.

The TH is calculated in mg/L by the following equation [30]:

$$TH = (2.497Ca^{2+} + 4.115Mg^{2+}) \text{ mmol}$$

In our area study, TH ranges from 60 to 180 mg/L with an average of 98 mg/L (Table 1). According to classification of [31], 1 water point belongs to the hard class (150-300 mg/L), 8 water points belong to medium hard class (75-150 mg/L) and 4 water points are considered to belong to freshwater class (< 75 mg/L). However, all TH values are all included in maximum permissible value range (TH mg/L: 100-500) recommended by world health organization [32].

3.1.2 Anions

Bicarbonate levels vary between 78.10 mg/L and 219.6 mg/L respectively in F2 and F7 boreholes with an average 119.56 mg/L (Table 1). The bicarbonate ion represents the dominant anion in our waters; it represents 75% of all anions (Fig. 4B) and 53% of all ions (Fig. 4C). Chloride contents range from 13 mg/L to 40mg/L respectively in F2 and F7 boreholes as in the case of bicarbonates, with an average of 21.75 mg/L. In terms of percentage, this ion comes in second place after bicarbonates; it represents 15% of all anions (Fig. 4B) and 10% of all ions (Fig. 4C). Sulphate levels range from 1.5 mg/L to 14 mg/L, respectively. In F3 and F4 boreholes with an average of 6.33 mg/L, it represents 6% of all anions (Fig. 4B) and 3% of all ions (Fig. 4C). As for nitrates that vary between 1.3 mg/L and 28.10 mg/L respectively in drilling at F9 and F7 with an average of 7.35 mg/L, they represent 4% of all anions (Fig. 4 B) and also 4% of all ions (Fig. 4C).

3.1.3 Cations

The calcium ions, which represent most abundant cations in our waters, have contents between 19.20 mg/L and 54.40 mg/L respectively in the F2 and F7 boreholes with an average of 29.22 mg/L (Table 1).

They represent 46% of all cations (Fig. 4A) and 14% of all ions (Fig. 4C). In terms of abundance, calcium is followed by sodium with contents between 16 mg/L and 38 mg/L respectively in boreholes F2 and F7 with an average of 22.33 mg/L (Table 1). Sodium ions account for 37% of all cations (Fig. 4A) and 11% of all ions (Fig. 4C).

Magnesium contents range from 1.90 mg/L to 10.70 mg/L respectively in F11 and F7 boreholes with an average of 5.41 mg/L. This ion accounts for 11% of all cations (Fig. 4A) and 3% of all ions (Fig. 4C). Potassium levels are between 1 mg/L and 7 mg/L respectively in F2 and F7 boreholes with an average of 2.92 mg/L. This ion represents 6% of all cations (Fig. 4A) and 2% of all ions (Fig. 4C).

For characterization of water chemical facies, we used Piper diagram (Fig. 5). In the triangle of cations five water points (F1, F4, F5, F6, F12), or 38.46% of all water points analyzed are located at the level of calcium pole; seven water points (F2, F3, F7, F8, F9, F10, F13), or 53.84% of water points analyzed are located at the pole dominated by no cations; and finally a point (F11) or 7.7% of water points analyzed are located at the level of sodi-potassic pole. In the triangle of anions, almost all waters (100%) are at the bicarbonate pole level. The projection of the points in diamond of the piper diagram made it possible to differentiate two families of waters: a first family with a facies bicarbonate-calcium (92.3%), and a second family with a bicarbonate-sodium and potassium facies (7.7%).

The mineralization mechanism of these waters is essentially of natural origin and the correlation matrix (Table 2) seems to support this hypothesis. Indeed, the strong correlation between the ions HCO_3^--Na^+ (0.95) and HCO_3^--K^+ (0.90) as well as moderate correlation between HCO_3^--Ca^{2+} (0.43) and HCO_3^--Mg^{2+} (0.59), suggests the natural origin of these ions. Indeed, these ions would come from hydrolysis of silicates. The moderate correlation between Ca^{2+}-Na^+ (0.49) suggests the presence of exchanges between these two ions. In addition, the strong correlation between the ions

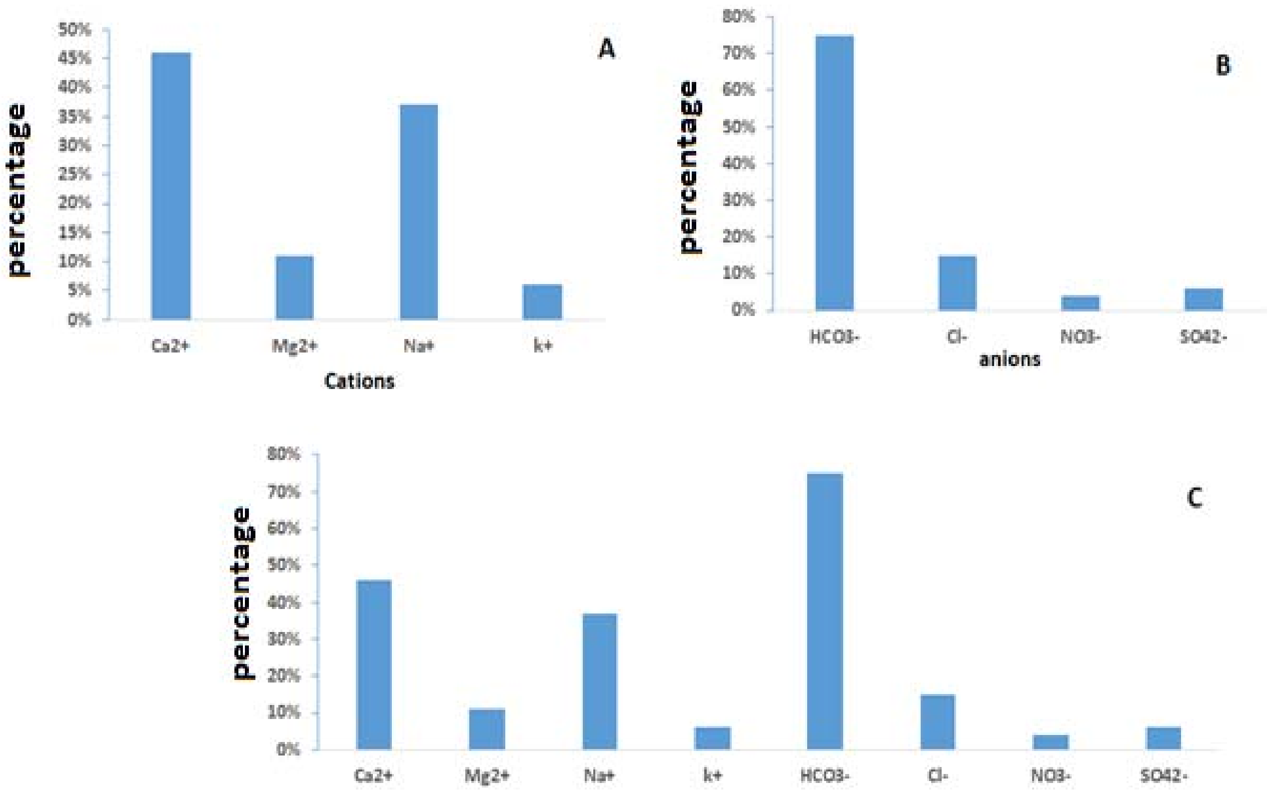

Fig. 4 Statistical distribution of major water ions.

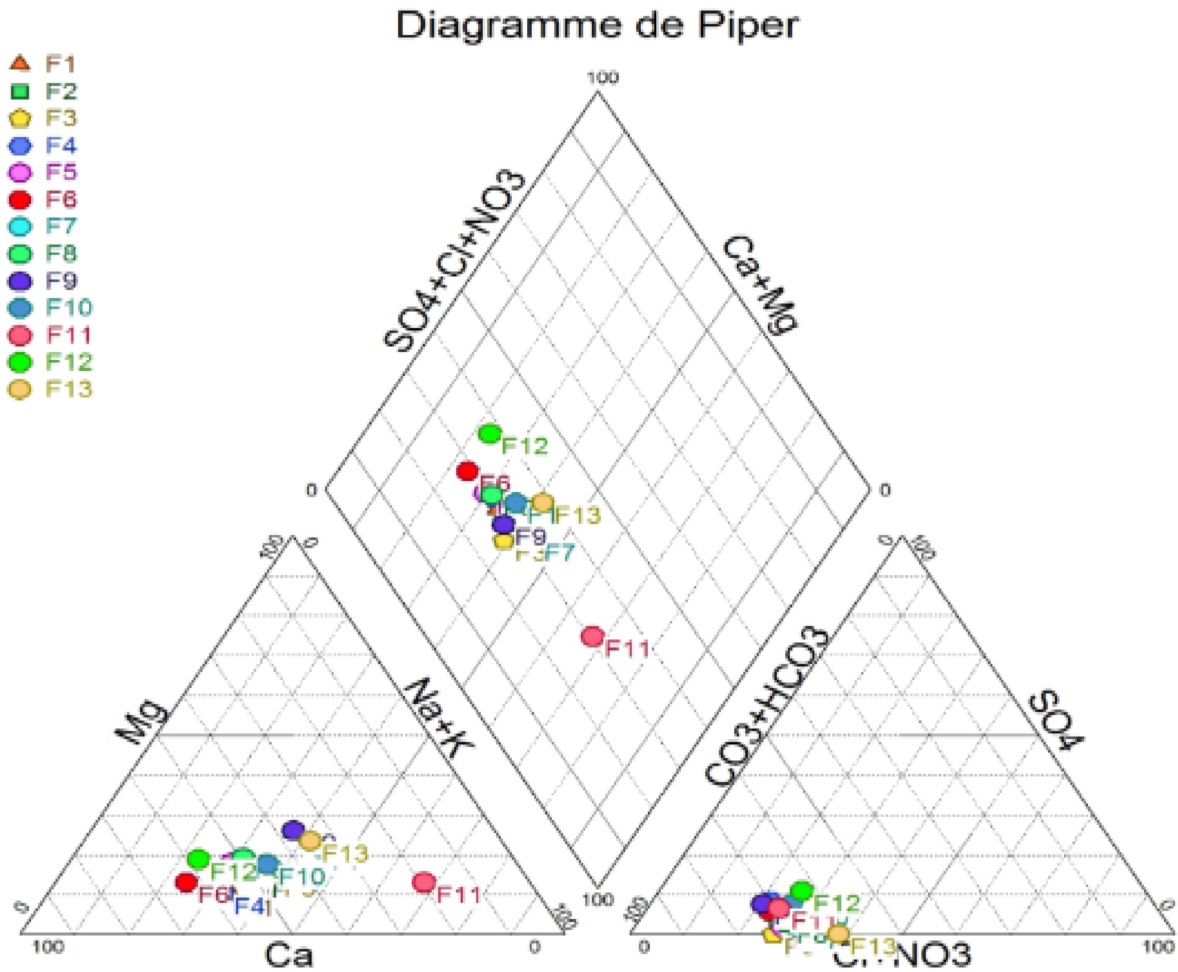

Fig. 5 Diagram of waters of different water boreholes of schools.

Table 2 Correlation matrix.

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	CE	pH
Ca^{2+}	1								
Mg^{2+}	0.56	1							
Na^{+}	0.49	0.69	1						
K^{+}	0.44	0.70	0.92	1					
HCO_3^-	0.43	0.59	0.95	0.90	1				
Cl^-	0.45	0.61	0.96	0.92	0.98	1			
SO_4^{2-}	0.51	0.44	0.35	0.37	0.32	0.25	1		
CE	0.16	0.38	0.38	0.41	0.44	0.41	-0.01	1	
pH	0.17	-0.2	-0.2	-0.48	-0.31	-0.31	0.21	-0.38	1

Cl^--Na^+ (0.96), Cl^--HCO_3^- (0.98), Cl^--K^+ (0.92) and the moderate correlation between Cl^--Ca^{2+} (0.45), Cl^--Mg^{2+} (0.61) reflects a mineralization related to the influence of temperature. In Conclusion, we retain that the chemism of these waters probably results from the combined action of the hydrolysis of silicates, basic exchanges, and the influence of temperature.

3.1.4 Assessment of Water Potability

To assess quality of the water in our study area we referred to quality standards based on physico-chemical and bacteriological parameters. Because in order to define potability of a water, standards have been established, and each parameter is assigned a guide value not to be exceeded in order to avoid human health problems. This is how a water intended for consumption must also be clear, be colourless and have no unpleasant taste or odour. In addition, it must not contain germs of waterborne diseases, toxic substances or excessive amounts of mineral and organic matter. In addition, drinking water must contain without excess of a number of mineral elements whose presence is necessary for body. However, the fact that a water complies with the standards, i.e. drinking, does not mean that it is free of polluting materials, but it does mean that their concentration has been considered low enough not to endanger the health of the consumer [33].

3.1.5 Chemical Quality of Water

The results of physico-chemical analyses were also compared with the chemical composition of certain mineral waters sold in shops and with WHO's guide values [34]. It can be seen that values of ions Ca^{2+}, Mg^{2+}, HCO_3^- and SO_4^{2-} fall within the range of values of commercial waters, in addition the values are all below who-eligible standards for drinking water in all boreholes. The same observation was made for the K^+ ion with exception of drilling F7 in which the content obtained is very slightly higher than the range of values of commercial waters while remaining below WHO standards. NO_3^- ions have values greater than the range of commercial water values in 6 water points (F1, F2, F7, F8, F12 and F13). However, these values remain well below WHO standards.

3.1.6 Bacteriological Quality of Water

Bacteriological analysis makes it possible to highlight fecal water pollution. In nature pathogenic germs are very numerous and varied and it is not always easy to do specific research. Most of time, we prefer to look for germs that are always present in large numbers in the fecal matter of humans and warm-blooded animals and that are more easily maintained in external environment. In the case of this study, we are limited to the search for TC, *Escherichia coli* (*E. coli*), *Fecal enterococci* and FAT.

TCs have long been used as indicators of microbial water quality because they can be indirectly associated with faecal pollution. Most species are non-pathogenic and do not pose a direct health risk, with the exception of some strains of *Escherichia coli* (*E. coli*) as well as rare opportunistic pathogenic bacteria [34, 35].

Escherichia coli (*E. coli*), the species most commonly associated with the fecal coliform group, which is itself considered a subgroup of total coliforms, is the best indicator of faecal water contamination [35], which, depending on its origin, carries a greater or lesser risk of enteric infection [36]. *Fecal enterococci* is often found in the gastrointestinal tract of humans and many animals and the vast majority of these enterococci, especially those found in the wild, do not have a particular pathogenic power towards humans; rather, they are opportunistic pathogenic microorganisms infecting people at risk such as immunocompromised [38, 39]. Since generally the *Enterococci* does not proliferate in a distribution system, their presence in groundwater indicates pollution from faecal sources [35, 40]. For example, they have recently been recognized as indicators of faecal contamination of groundwater [36].

FAT, also referred to as total germs, represents all native and non-native microorganisms capable of multiplying at a temperature that varies between 22 and 40 °C [41]. The FAT is used as an indicator of the overall load and the count of these germs, allows estimating the density of the general bacterial population in drinking water. It thus allows an assessment of overall safety of water, but does not determine the sources of contamination [42]. We note from our analyses that all our water samples contain the FAT with concentrations that vary between 12 and 42 CFU/100 mL with an average of 26 CFU/100 mL (Fig. 6). The presence of these total germs in our waters could be due to the poor protection of these structures. In all cases, all of these drillings must be regularly monitored to see if there is not an increase in these germs over time. And in particular during the recharge of water table in the rainy season, because

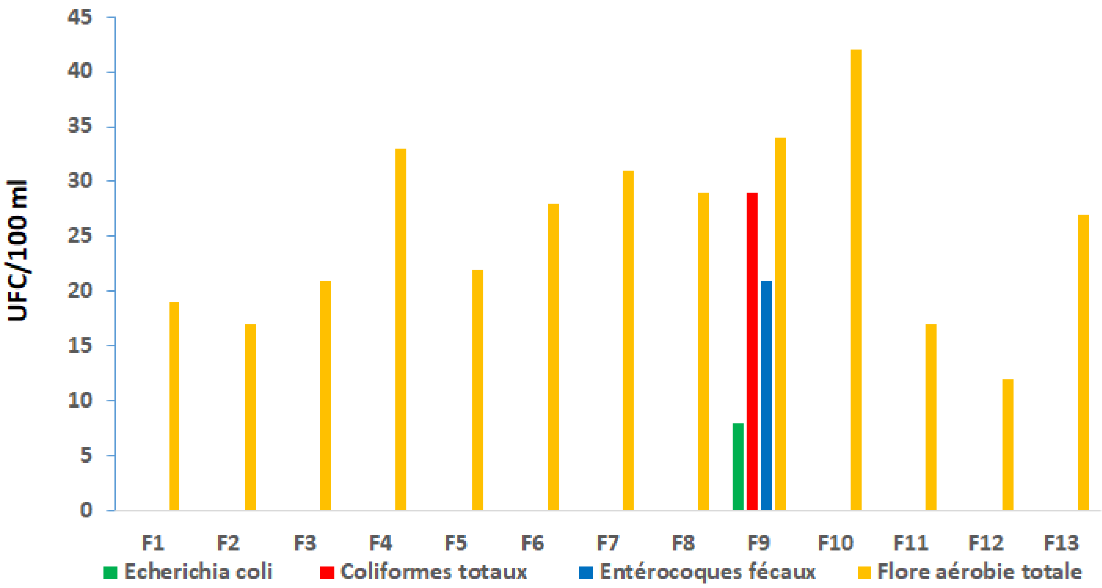

Fig. 6 Distribution of germs counted in borehole water.

according to Figarella and Leyral [43], if the number of total germs increases significantly, especially after heavy rain, it shows that the resource is poorly protected, and it is contaminated by infiltration water.

On the other hand, the other three germs including *Echerichia coli*, total coliforms and fecal enterococci are absent in almost all boreholes with the exception of drilling F9 (Fig. 6) where they are found at concentrations of 8, 29 and 21 CFU/100 mL respectively.

In view of the results of the bacteriological analyses obtained from our samples, we note that borehole 9 is unfit for consumption, because according to the WHO standard water intended for consumption must not contain any *Escherichia coli*, no TC, nor enterococci per 100 mL of water. Their presence in the waters borehole F9 suggests contamination of water of this drilling by feces, this contamination would be due to the defective sanitation system. The presence of a cesspool near the borehole will be the main source of these germs in the waters.

4. Conclusion and Outlook

At the end of this study, which focused mainly on the physico-chemical and microbiological quality of water intended for consumption in schools in N'Djamena city. In particular, for borehole water, we were able to make some observations:

- The study of physico-chemical quality of waters shows that from a qualitative point of view, the pH values meet the standards (6.5-8.5). The same applies to EC values of these waters which remain within the standards (180 to 1,000 µS/cm) except for drilling F7 at which the value far exceeds maximum standard (1,546 µS/cm) and also the turbidity values that remain in the standards (≤ 5 NTU) except for F3 drilling which has an excessive value (9_NTU). The results of anion and cation analyses show that almost all waters are ideal for drinking water compared to WHO standards.
- The hydrogeochemical study of waters makes it possible to say that waters are characterized by the presence of two dominant facies, which are the bicarbonate-calcium facies represented at 92.3% of the sampled water points, and a bicarbonate-sodium and potassium facies represented at 7.7% of the sampled water points. Water chemistry seems to be governed mainly by natural processes such as hydrolysis of silicates, basic exchanges, to which influence of temperature is added.

• From the bacteriological point of view, in about 8% of the borehole waters studied, the presence of faecal contamination germs is noted. This water soiled by fecal contamination germs should not be consumed without prior treatment. In addition, in all wells without exception, the presence total of germs is noted. The presence of these germs in boreholes is likely due to the failure of sanitation and household waste collection services.

At end of this study, we recommend the following:

• Treat water with sodium hypochlorite before consumption;

• Carry out seasonal monitoring of physico-chemical and bacteriological parameters;

• Implant watertight bottom latrines or reduce the depths (< 10 m) at expense of the latrines with a bleed that comes into contact with the tablecloth and pollute it;

• Increase the depths of action of boreholes to the level of the captive aquifer where the waters would be bacteriologically more protected;

We recommend better collaboration between the Ministry of Health and the Ministry of National Education to improve water quality in public schools.

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