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Effects of Latrines on Water Quality in the Phreatic Nappe in N'Djamena City: (5th District), Chad

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Abstract

Water is a precious natural resource, essential for many uses (crucial for various purposes). Its use for food or hygiene purposes requires excellent physicochemical and microbiological quality. The region has a high population density compared to other cities in Chad. In order to determine the effect of latrines on groundwater quality in the N'Djamena city, specifically in the 5th district, 13 water points were selected for physicochemical and bacteriological analyses. Physico-chemical parameters such as pH, temperature and conductivity were measured *in situ* using a multi-parameter device. Major ion analysis was carried out at the ***Laboratoire National des Eaux in N' Djamena***. Anions (Cl^-, SO_4^{2-}, NO_3^-) were analysed using a Dr6000 spectrophotometer, and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) using a flame photometer and a volumetric dosing method. The result show that, the pH ranged from 5.89 to 6.78, with an average of 6.40. EC values range from 441 μS/cm to 1647 μS/cm, with an average of 830.76 μS/cm. A temperature values vary from 29˚C to 32˚C, with an average of 30˚C. The turbidity values range from 0.48 NTU to 10.6 NTU, with an average of 2.30 NTU. Ca^{2+} range from 20.8 mg/L to 160 mg/L, with an average of 73.23 mg/L (20). Mg^{2+} ranged from 3.4 mg/L to 18 mg/L, with an average of 6.85 mg/L. The Na^+ ranged from 1.8 mg/L to 14.5 mg/L with an average of 3.83 mg/L. The iron content ranges from 0.06 mg/L to 0.83 mg/L, with an average of 0.29 mg/L. The average values are compared with world health organisation (WHO) drinking water quality standards. The results of chemical analyses on the Piper diagram show that the dominant chemical facies are calcium-magnesium bicarbonate. Bacteriological parameters were analysed using the membrane filter method. The samples contained *E. coli*, total coliforms and aerobic flora in excess of the WHO norm. The microbiological analyses clearly confirmed a high concentration of germs in the borehole water. Because the distance between the latrines and the water points was not respected, the pathogenic germs reached the water table, making the groundwater unhealthy. As a result, suitable water treatment is required before drinking form.

Keywords

Latrines, Groundwater Quality, 5^{th} District/N'Djamena, Chad

1. Introduction

Groundwater is the primary source of drinking water for large cities in approximately most African countries. Water, a vital and limited resource is essential to life and all human activity. It is used for domestic, agricultural and industrial purposes [1]. Humans depend on the availability and quality of this limited and fragile resource [2]. Human activities are increasingly responsible for the introduction of a large number of chemical substances into the ground, making groundwater resources vulnerable. Groundwater contemplated to be cleaner and safer, relative to the surface water owing to its natural soil benefits act as natural filter for variety of the contaminants [3]. However, the use of pit latrine without considering building construction guidelines may lead to groundwater contamination. Human faeces contain a large number of microbes, including bacteria, viruses, microbial eukarya and potentially protozoa [4] [5]. Groundwater is also threatened by the infiltration and transport of pollutants. These substances may originate from the diversification of agricultural and industrial activities and the discharge of partially treated wastewater [6]. Worldwide, 80% of diseases are attributed to a lack of clean water and inadequate sanitation [7]. Diseases caused by polluted drinking water kill 3.1 million people a year, 90% of them children under the age of five. Access to good-quality water is therefore becoming an ongoing quest to prevent certain water-related diseases. In Chad, the lack of drinking water in certain regions is not only a serious health problem, but also a breeding ground for diseases such as cholera and typhoid fever. Many people live in poor sanitary and hygiene conditions. There are also virtually no sewerage systems to collect and dispose all the water, regardless of its source [8].

The Ndjamena city, like all developing countries Africa's major cities, is also experiencing rapid population growth. This can lead to risks of groundwater contamination, linked to human activities [9]. Sewerage systems, latrines, septic tanks, factory wastewater and solid waste are the main sources of groundwater pollution in the urban sector [10]. The poor sanitation is a major factor facilitating to the ongoing high rate of diarrhoeal disease and cholera in third world countries [11]. Groundwater plays a major role in the supply of drinking water and the development of irrigation. However, the lack of hygiene and the poor quality, especially bacteriological, of groundwater are responsible for the appearance and spread of water-borne diseases. Therefore, this study aims to assess the impacts of the latrines on groundwater quality.

Specifically, we need to understand (i) levels of physio-chemical and bacteriological parameters in groundwater wells vicinity to the pit latrines, (ii) how the variation of distance from the pit latrine to the well could affect the groundwater quality. With this in mind, we will attempt to determine the impact of latrines on the water table.

2. Presentation of the Study Area

The city of N'Djamena is located between 12.002˚ and 12.286˚ north latitude and between 14.848˚ and 15.287˚ east longitude as showing in (**Figure 1**). The area covered by this study is the commune of the 5th arrondissement, in the center of the city of N'Djamena, with a surface area of 63,000 km^2 and an estimated population of 100,948 [12]. This district has three (3) neighbourhoods: **Ridina, Amriguebé** and **Champs de fils**. It lies in a semi-arid zone, with a long dry season (October to May) alternating with a short rainy season (June-September). Rainfall varies between 226 and 990 mm, with an annual average of 584 mm, while temperatures fluctuate between 28˚C and 47˚C [13]. The city is drained by the tropical Chari and Logone rivers, part of the Lake Chad basin. The city of N'Djamena is underlain by Terminal Continental (TC) formations, which are in places covered by Plio-Quaternary formations. These formations are very heterogeneous and present, from top to bottom: clayey-silty levels with sandy layers between 0 and 10 m; a succession of sandy, clayey-sandy layers with clay lenses between 10 and 60 m; impermeable clays between 60 and 75 m [14]. The impermeable to semi-permeable clay levels form the walls of the aquifers [15]. The lower limit of the

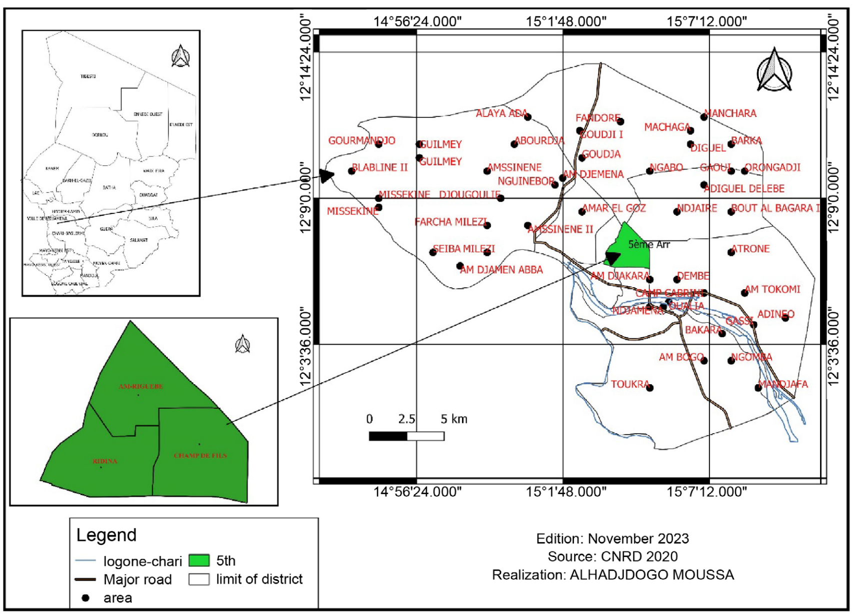

Figure 1. Map of the study area.

subsurface aquifer is represented by clay banks at a depth of around 20 m and the wall of the deep aquifer is located at a depth of between 60 and 75 m [16] [17]. The piezometric surface lies between 10 and 15 m below ground [18] [19].

- The climates parameters

Studied parameters are precipitation, temperature, humidity, insolation and evaporation. These parameters make it possible to judge the influence of the climate on the formation and renewal of water resources both in quantity and quality, which parameters condition surface and underground flow. These data are provided by the National Agency of Meteorology (ANAM) 1990-2020. The city of N'Djamena is subject to a dry and hot semi-arid climate. Consequently, the rains depend exclusively on the position and structure of the ITCZ and are mainly of convective origin and come from an isolated cumulonimbus or a cloud formation developing in the form of a squall line that generally moves from East to West across the Sahelian region. Precipitation is the main source of groundwater reserves. It allows an indirect assessment of the state of soil water reserves, recharge and the flow regime of watercourses in the watershed. In order to monitor the distribution of precipitation during the hydrological year, we calculated the average annual rainfall over the thirty years recorded. The rainfall varies greatly from one year to the next. Very dry years (1990, 1997) can be distinguished with water level of 296.2 and 422.1 mm respectively and fairly wet years (1998, 2020) with water levels of 775.9 and 831.2 mm respectively as showing in (**Figure 2**).

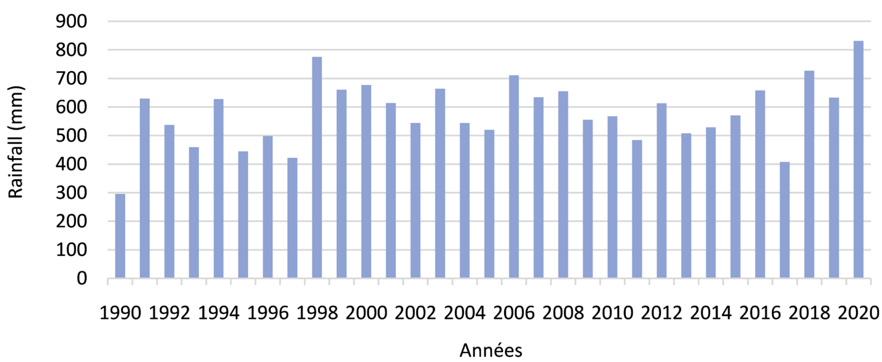

Figure 2. Average annual rainfall 1990-2020 (ANAM).

Geological and Hydrogeological Context

The geology of the Chari Baguirmi region in general and that of the city of N'Djamena in particular is linked to that of the Lake Chad Basin [14] [17] [19] [20]. The Chari Baguirmi region is underlain by Quaternary alluvium from the former Lake Chad. These alluvial deposits are superimposed on the Precambrian crystalline soil. Its stratigraphy distinguishes sedimentary deposits of fluvial, lacustrine or eolian origin during the Quaternary formation as shown in **Figure 3**. The area is made up of sedimentary formations of sands, clays and silts from the Quaternary. The sands are particularly well developed in the central part of the basin, on the riverbeds of the Logone-Chari and in the south of Kanem.

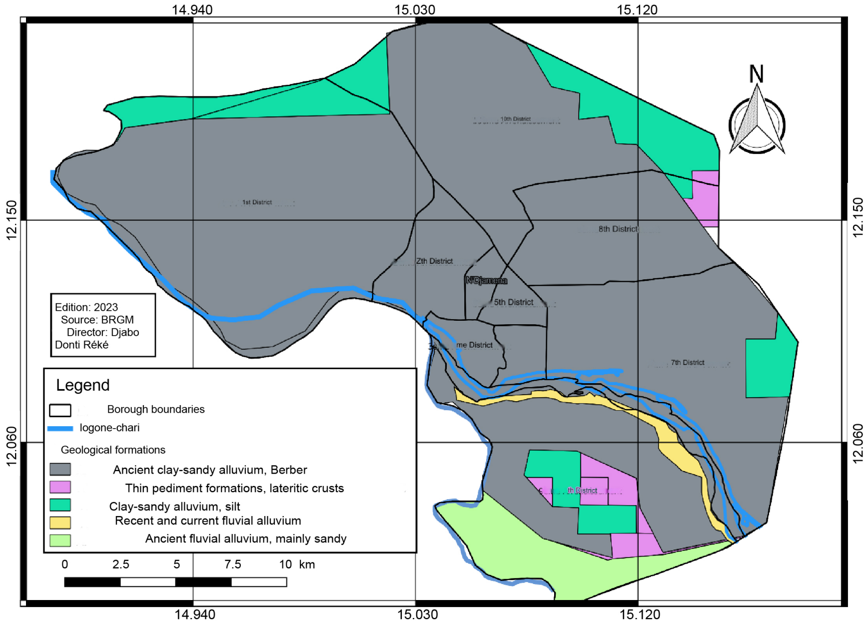

Figure 3. Geological map in scale of 1:1,500,000 after (BRGM).

We found in the N'Djamena city:

- Ancient sandy-clay alluvium;
- Recent and current fluvial alluvial deposits;
- Shallow sedimentary formations, lateritic cuirasses;
- Ancient fluvial alluvial deposits, mainly sandy.

Hydrogeological studies previously carried out in the Lake Chad basin [16] [19] [20]-[25]. list the different aquifers, their water resources, their geometric characteristics as well as the chemical and isotopic characteristics of their groundwater. The analysis of hydrogeological sections shows a system of superimposed aquifers shared between Chad, Cameroon, CAR, Niger and Nigeria [26]. According to [14], 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. The N'Djamena city is located in a very flat alluvial plain along its entire south edge by the Chari River. This, the largest in Chad, has its source in Mount Yade. It is joined by its main tributary, the Logone, near the town; the latter takes its source in the Adamaoua massif in Cameroon. As a result, these rivers have a tropical regime acquired largely in their upstream course outside the borders of Chad, and they result from the association of several watercourses [20].

3. Methodology

3.1. Sampling of Water Points

Two approaches make up this component. The first consists of measuring *in situ* the physical parameters of the water in the study area, such as temperature, hydrogen potential (pH) and the electrical conductivity (EC) of the structure (borehole). The second approach involves actual sampling to analyse chemical and bacteriological parameters in the laboratory. A total of 13 hydraulic structures were sampled. The samples were taken in the 5th arrondissement of N'Djamena as showing in (Figure 4). All measured distance between water point and latrine are less than 15 m as recommended by WHO as shown in Table 1 and Figure 5. This is without the neighbour's latrine point who must be also far from water point.

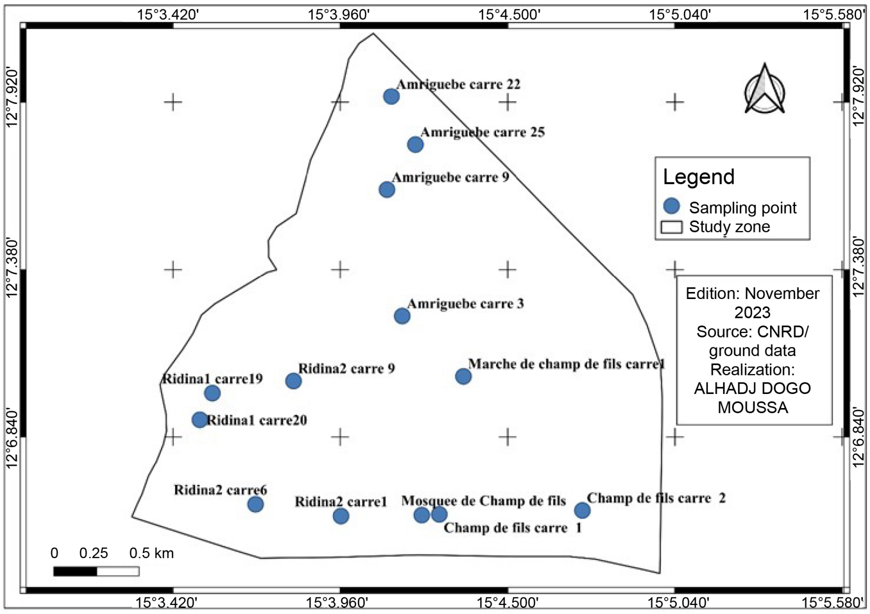

Figure 4. Sampling map of water point.

Table 1. Measured distance between latrine and waters points.

Location	Distance measured
Unit	M
Ridina 2 square 6	3.4
Ridina 1 square 19	2
Ridina 2 square 1	1.5
Ridina 1 square 20	3
Ridina 2 square 9	10
Champ de fils square 2	7
Champ de fils square 1	5
Mosquée de Champ de fils	4
Marché de champ de fils square 1	6.5
Amriguebé square 3	6
Amriguebé square 9	3.8
Amriguebé square 22	7
Amriguebé square 25	4

(a) (b)

Figure 5. (a) image of insalubrious well; (b) measured distance between well and latrine.

The samples intended for physicochemical analysis were collected directly from the boreholes in 500 ml bottles and were first analysed in situ (pH, electrical conductivity, temperature) before being brought back to the laboratory.

The manoeuvre for the in-situ analysis is simple: rinse the electrodes of each device with distilled water; dip them into a beaker containing around 100ml of the sampled water, and the results are obtained directly by simply reading the digital screen. Samples for laboratory analysis were stored in polyethylene bottles. Major ion analysis was carried out at the ***Laboratoire National des Eaux in N'Djamena***. Anions (Cl^-, SO_4^{2-}, NO_3^-) were analysed using a volumetric assay and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) using a DR6000 spectrophotometer and a flame photometer.

The bacteriological analyses are designed to detect and count pathogenic germs and pollution indicators, such as total coliforms, *Escherichia coli*, faecal enterococci and aerobic flora. These germs were determined using the membrane filter method.

3.2. Statistical Processing of the Data

To process the results of the analyses, we used the piper diagram to identify the different types of groundwater and to define the plausible hydro chemical processes that govern the chemistry of these waters, and Principal Component Analysis (PCA), which is a method of descriptive statistical analysis of multidimensional data. Its aim is to establish a relationship between several chemical variables and to group together those that show similar behaviour.

4. Results

4.1. Physico-Chemical Characteristics of Waters

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 5%. The results of the statistical analyses of the physico-chemical data are presented in **Table 2**.

Table 2. Results of statistical analysis of physico-chemical data.

Parameters	Unit	Min	Max	Moy	Ecart-Type	Error-type	CV	Norm WHO/CHAD
PH à 25˚C		5.89	6.78	6.4	0.23	0.07	0.04	**6 ≤ pH ≤ 8.5**
CE	µs/Cm	441	1647	830	390.88	108.41	0.47	**≤2500**
T˚	˚C	29	32	30.74	0.76	0.21	0.02	**8 ≤ T ≤ 25**
Turbidité	NTU	0.48	10.6	2.3	2.68	0.74	1.17	**≤1300**
TSD	mg/l	136.4	527	264	128	35.57	0.49	**≤1300**
TH	mg/l	20	548	209	149	41.41	0.71	**not mentioned**
Ca^{2+}	mg/l	20.8	160	73.23	45.37	12.58	0.62	**≤200**
Mg^{2+}	mg/l	3.4	18	6.85	4.68	1.30	0.68	**≤50**
K^+	mg/l	0.2	3.4	1.55	1.00	0.28	0.64	**≤12**
Na^+	mg/l	1.8	14.5	3.84	3.42	0.95	0.89	**≤200**
NH_4^+	mg/l	0.01	0.65	0.20	0.20	0.06	1.02	**≤1.5**
Cl-	mg/l	4	60	13.77	14.83	4.11	1.08	**≤250**
SO_4^{2-}	mg/l	1	26	9.38	9.00	2.50	0.96	**≤250**
NO_3^-	mg/l	1.3	17.8	5.30	4.82	1.34	0.91	**≤250**
HCO_3^-	mg/l	68.3	505	231.24	140.74	39.03	0.61	**Not mentioned**
Fe	mg/l	0.06	0.83	0.30	0.22	0.06	0.75	**≤0.3**

4.1.1. Physical Parameters

The pH is one of the most important parameters for water quality. It characterises a large number of physico-chemical equilibria and depends on many factors, including the origin of the water. The pH of natural water is linked to the nature of the ground through which it flows [27]. For all the water points measured, the pH ranged from 5.89 to 6.78, with an average of 6.40 (**Table 2**). Conductivity: Electrical conductivity reflects the mineralisation of water, which also depends on the aquifer formation and the residence time of the water in these formations. Conductivity values range from 441 µS/cm to 1647 µS/cm, with an average of 830.76 µS/cm (**Table 2**). Temperature: It is important to know the precise temperature of the water, as it plays an important role in the dissolution of dissolved salts. It also influences the multiplication of micro-organisms and their metabolism. A temperature that is too high encourages the growth of micro-organisms [7]. Values measured in the field vary from a minimum of 29˚C to a maximum of 32˚C, with an average of 30˚C (**Table 2**). Turbidity: The turbidity of water is due to the presence of particles and colloids in suspension or suspended matter, in particular clays, silts, grains of silica, organic matter, etc. The more effective the water treatment, the lower the turbidity. The more effectively the water has been treated, the lower the level [27]. Values range from 0.48 NTU to 10.6 NTU, with an average of 2.30 NTU (**Table 2**). Dissolved solids content (TDS): The dissolved solids content or dissolved salts content varies significantly depending on the sampling point. The water analysed had TDS values ranging from 136.4 mg/L to 526.9 mg/L, with an average of 264.02 mg/L (**Table 2**).

4.1.2. Chemical Parameters

Calcium Ca^{2+}: Calcium is generally the dominant element in drinking water and its content varies essentially according to the geological nature of the ground through which the water flows (limestone or gypsum) [28]. The results obtained show that calcium levels range from 20.8 mg/L to 160 mg/L, with an average of 73.23 mg/L (20) (**Table 2**). Magnesium Mg^{2+}: Magnesium is a significant element in water hardness, its content depending on the composition of the sedimentary rocks encountered (dolomitic limestones, dolomites), as it is also present in marine waters [29] and even in certain pesticides. In this study, magnesium levels ranged from 3.4 mg/L to 18 mg/L, with an average of 6.85 mg/L (**Table 2**). Sodium Na^+: Sodium in water generally comes from leaching of geological formations, dissolution of halite and marine waters, saline soil, pesticides, animal waste, and domestic wastewater discharges [30]. The levels of Na^+ in the water analysed ranged from 1.8 mg/L to 14.5 mg/L with an average of 3.83mg/L (**Table 2**).

Ammonium (NH_4^+): Ammonium is the product of the final reduction of nitrogenous organic substances and inorganic matter in water and soil. It also comes from the excretion of living organisms and the reduction and biodegradation of waste, not forgetting inputs from domestic, industrial and agricultural sources. Ammonium levels in the water analysed ranged from 0.01 mg/L to 0.65 mg/L, with an average of 0.19 mg/L (**Table 2**). Iron (Fe): The presence of iron in water can have a natural origin (leaching of clay soils) or an industrial origin (in the metallurgical or iron and steel industries) [31]. The iron content values obtained in the water analysed range from 0.06 mg/L to 0.83 mg/L, with an average of 0.29 mg/L (**Table 2**).

Total hardness (TH): Hardness is a natural characteristic linked to the leaching of the ground through which the water flows and corresponds to the calcium and magnesium content. For this analysis, levels ranged from 20 mg/L to 548 mg/L, with an average of 209.69 mg/L (**Table 2**).

Nitrates NO_3^-: Nitrates (NO_3^-) are naturally occurring ions present everywhere in the environment Sources of nitrates in water (particularly groundwater) include decaying animal and plant matter, agricultural fertilisers, manure, domestic wastewater and geological formations containing soluble nitrogen compounds [32]. Nitrate levels for the studied waters vary between 1.4 mg/L and 17.8mg/L with an average of 5.3 mg/L.

Chlorides (Cl^-): Chlorides are always present in natural waters, but in variable proportions. They are mainly derived from the dissolution of natural salts by the leaching of saliferous soils, and from domestic and industrial wastewater discharges [33]. The chloride values obtained for the borehole water studied range from 4 mg/L to 60 mg/L, with an average of 13.76 mg/L (**Table 2**).

Sulphates (SO_4^{2-}): Sulphates (SO_4) can be found in almost all natural waters. The origin of most sulphate compounds is the oxidation of sulphite ores, the presence of gypsum, or urban or industrial waste. The sulphate values obtained for the waters studied range from 1 mg/L to 26 mg/L, with an average of 9.38 mg/L (**Table 2**).

Bicarbonates (HCO_3^-): The bicarbonate and calcium ions found mainly in natural water originate from the dissolution of calcium carbonate (calcite or aragonite) by the carbon dioxide dissolved in the water and come from the atmospheric air. WHO standards do not set a concentration limit for this parameter. The values obtained for this study range from 68.3 mg/L to 505.1 mg/L, with an average of 231.23 mg/L (**Table 2**).

Chemical facies of the water: The representation of the results of the chemical analyses on the Piper diagram (**Figure 6**) shows that the dominant chemical facies are calcium-magnesium bicarbonate in the water samples. It is characterised by a predominance of bicarbonate ions and magnesium cations.

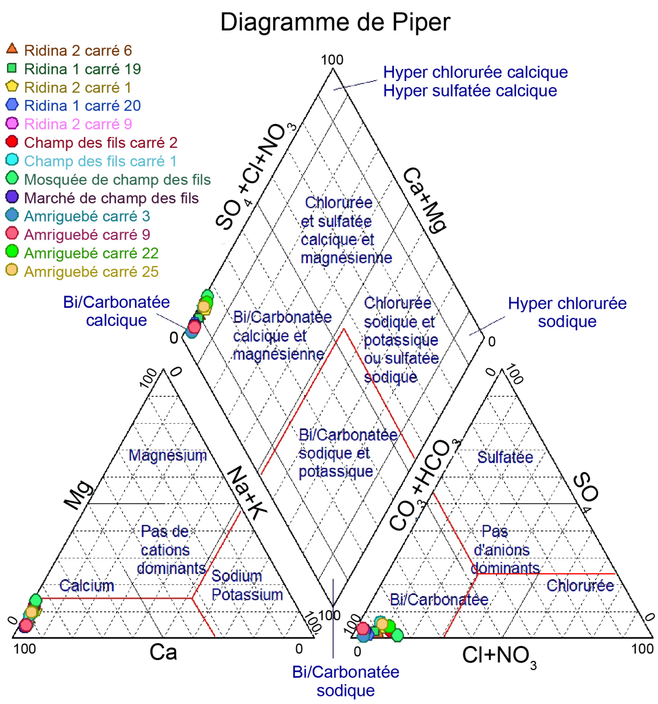

Figure 6. Piper diagram indicates the facies of studied water.

4.1.3. Bacteriological Parameters

The bacteriological parameters determined as part of this study are: Total coliforms, *Escherichia coli* (*E. coli*), *Enterococci* and *Aerobic flora*. These results are shown in **Table 3**. Total Coliforms Total coliforms are a much larger group of bacteria that are present in the feces of humans and warm-blooded animals. They are also present in most untreated sources and in waters enriched with organic matter. The results of this analysis show that all the water points analyzed are contaminated (**Table 3**). *Escherichia coli* is the member of the total coliform group that is found exclusively in the intestines of mammals and humans. The possible presence of pathogens responsible for certain waterborne diseases. The results show that all the water points analyzed are contaminated (**Table 3**). Aerobic flora Aerobic flora are global germs that grow in the presence of oxygen at a temperature between 25˚C and 30˚C. The results show that all the water points analyzed are contaminated (**Table 3**).

Table 3. Bacteriological results.

Location	*Escherichia coli*	Presumed total coliforms	Faecal enterococci	Total aerobic flora
Unit	**UFC/100ml**	**UFC/100ml**	**UFC/100ml**	**UFC/100ml**
Ridina 2 square 6	184	19,200	0	23,400
Ridina 1 square 19	780	25,300	0	36,300
Ridina 2 square 1	1320	47,600	0	68,200
Ridina 1 square 20	920	46,800	0	57,200
Ridina 2 square 9	8420	14,900	0	33,400
Champ de fils square 2	852	34,000	0	78,400
Champ de fils square 1	189	15,300	0	38,400
Mosquée de Champ de fils	322	38,800	0	79,000
Marché de champ de fils square 1	1005	30,400	0	48,000
Amriguebé square 3	145	27,200	0	38,000
Amriguebé square 9	3870	62,400	0	78,000
Amriguebé square 22	642	43,600	0	68,000
Amriguebé square 25	789	33,200	0	52,000
Min	**145.00**	**14900.00**	-	**23400.00**
Max	**8420.00**	**62400.00**	-	**79000.00**
Ecart-type	**2290.76**	**13960.64**	-	**19184.54**
WHO/CHAD	Can not founded on 100 ml			No directive for drinking water

5. Discussion

The pH values recorded in the districts (**Ridina 2** square 6, **Ridina 2** square 9, ***Champ des fils*** square 1, **Amriguebé** square 3, **Amriguebé** square 9, **Amriguebé** square 22 and **Amriguebé** square 25) mentioned above (**Figure 3**) are below the minimum value (6.5) permitted by the Chadian national standard/WHO guidelines. These pH values can be explained by the nature of the rocks through which the groundwater flows. When water infiltrates the ground, it interacts with the components of the rocks it passes through. The acidic nature of the water in these areas seems to be linked to the nature of the aquifers, which are essentially made up of siliceous soil. According to [34], the siliceous nature of the aquifers explains the acidic nature of the water. The dissociation of carbonic acid from CO_2 in the atmosphere is one of the factors contributing to the acidification of the groundwater concerned (surface aquifer).

This result is in line with that obtained by [35] who found pH values lower than the minimum value (6.5) in some districts of N'Djamena allowed by the Chadian national standard/WHO Guidelines.

Measuring conductivity is a good way of assessing the degree of mineralisation of water, where each ion acts through its concentration and specific conductivity. The conductivity values of the water analysed vary between 441 µS/cm and 1647 µS/cm, with an average of 830.76 µS/cm. These values comply with standards and are below the limit set by WHO/Chad (2500 µS/cm). However, when compared with the [36], the values observed in the **Ridina 2** square 9, ***Champ des fils*** square 1, **Amriguebé** square 9, **Amriguebé** square 22 and **Amriguebé** 25 neighbourhoods are higher than the standard. According to the classification made by [27], water with an electrical conductivity greater than 1000 µS/cm is highly mineralised and unfit for human consumption. According to [37], the high conductivity values could be explained by infiltration of groundwater by wastewater from septic tanks.

The distribution of temperature values shows in most cases they temperature are concentrated between 29˚C and 32˚C, with an average of 30˚C. In most Sahelian regions, at a depth of less than 30 m, the groundwater temperature is approximately equal to the average air temperature [38]. These results are similar to those of [9], who found temperature values ranging from 29.6˚C to 31.8˚C, with an average of 30.59˚C in the town of N'Djamena.

All the values obtained comply with the Chadian national standard/WHO guidelines, which stipulate that turbidity should be ≤ 5 NTU. Except for the value observed in the **Amriguebé** square 22 neighbourhood, which was higher than the standard at 10.6 NTU (**Table 2**). This high turbidity is due to the presence of suspended matter such as clay, silt and solid waste, which give the water a cloudy appearance.

The water analysed has TDS values ranging from 136.4 mg/l to 526.9 mg/l, with an average of 264.02 mg/l. These variations are probably due to the influence of urban discharges from septic tanks and the leaching of certain minerals from the soil.

A high Ca^{2+} content was observed in the Amriguebé 9, Amriguebé 22 and Amriguebé 25 districts. This high content can be explained by the nature of the aquifer, which is partly made up of limestone. The presence of Ca^{2+} in the samples analysed is directly linked to the geological nature of the ground traversed.

The values obtained comply with the Chadian/WHO national water standard, which stipulates that the maximum Ca^{2+} concentration ≤ 200 mg/l. The presence of these potassium concentrations is due to the rocks through which they pass. Potassium is a natural element in water, where its concentration, which is more or less constant, does not usually exceed 10 to 15 mg/l [29]. Furthermore, the values obtained in this study comply with the Chad National Standard/WHO Guideline, which stipulates that the potassium ion content in drinking water must be

≤12 mg.

The ammonium concentrations obtained in this study comply with the Chad National Standard/WHO Guideline, which stipulates that the sodium ion content in drinking water must be ≤1.5 mg/l. The iron concentration values recorded in the Ridina 2 square 6, Ridina 1 square 19, Amriguebé square 9 and Amriguebé square 22 neighbourhoods mentioned above are higher than the maximum value (0.3 mg/l) stipulated by the Chadian national standard/WHO guidelines. The high presence of iron in the water can be explained by the drilling equipment materials, corrosion of metal pipes (cast iron or steel).

As a result, high iron concentrations pose a health risk. The ingestion of large quantities of iron leads to haemochromatosis, a condition in which the normal regulatory mechanisms function insufficiently, leading to tissue damage caused by iron loading [39]. This result corroborates that of [35] who found iron concentration values higher than the maximum value (0.3 mg/l) in the water from manual boreholes in the town of N'Djamena.

The presence of NO_3^- observed in the neighbourhoods listed above can be explained by the nature of the soil. According to [40], nitrates are naturally present in the soil; they can penetrate it and reach the groundwater by infiltration.

According to the Chadian national standard/WHO guidelines, the NO_3 concentration must not exceed 50 mg/l. All the samples analysed comply with the standard, as the NO_3^- concentrations obtained remain low and below the limits of the standard.

The high concentration of SO_4^{2-} in the above-mentioned districts is due to the rocks through which the water flows. The geology in these areas is made up of sedimentary rock, gypsum ($CaSO_4$). According to [41], the presence of sulphate in unpolluted water suggests the presence of gypsum in concentrations ranging from 2.2 to 58 mg/l. Calcium and magnesium bicarbonate facies are characteristic of immature waters in sedimentary aquifers, and are found in all groundwater [24]. This could be explained by the fact that this facies defines groundwater close to the recharge zone.

Total coliforms are used as indicators of microbiological water quality because they can be indirectly associated with pollution of faecal origin. The number of total coliforms obtained in the water analysed was greater than 100 CFU/ml. The maximum total coliform value recorded for this study was 62,400 CFU/100ml (**Table 3**). This contamination is generally of anthropogenic origin, although warm-blooded animals also cause the same effects. This result corroborates that of [42], who found a total coliform value of over 100 in the water downstream of the Maroc valley.

According to WHO/CHAD, drinking water should not contain coliforms, *i.e.* 0 CFU/100ml. The presence of this pollutant in water can be the cause of waterborne diseases such as gastro-enteritis. The concentrations of Escherichia coli in the water analysed ranged from a minimum value of 145 CFU/ml observed in the Amriguebé neighbourhood, square 3, to a maximum value of 8420 CFU/ml observed in the Ridina 2 neighbourhood, square 9 (**Table 3**). The presence of Escherichia coli in high numbers indicates a deterioration in water quality, and their presence in the sample may mean that the water in these samples is considered unfit for consumption and should be disinfected. Their presence in the water indicates faecal contamination, probably due to the problem of septic tank installations near boreholes generating faecal pollution.

Furthermore, the *E. coli* concentration values obtained in the above-mentioned districts do not comply with the Chadian national standard/WHO guidelines, which indicate a total absence of *E. coli* in drinking water. The presence of faecal coliforms such as *E. coli* in water has consequences for consumer health. According to [43], *E. coli* bacteria are responsible for diarrhoea. This finding is in line with that of [1] who found *Escherichia coli* concentrations higher than the norm in Algerian groundwater. The total absence of faecal Enterococci can be explained by their persistence but also by the difficulties encountered in the laboratory. According to the analysis conditions, samples must be incubated at 37˚C for 48 hours (**Table 3**). The presence of these bacteria would be due to the infiltration of water loaded with organic matter to reach the water table. The aerobic flora content obtained in the study area is greater than 100 CFU/ml (**Table 3**). Compared with the WHO/TCHAD guideline, there is no guideline for drinking water. The presence of these germs can be the cause of several waterborne diseases.

6. Conclusions

At the end of this study entitled the effects of latrines on the groundwater quality in the N'Djamena city, the result gathered around some the following points.

The parameters investigated were physicochemical parameters such as pH, turbidity, conductivity, iron, calcium, etc., and microbiological parameters such as *E. coli*, total coliforms, enterococci and aerobic flora:

- The physico-chemical parameters were determined using well-defined methodologies, and it emerged that all the physico-chemical parameters comply with the current Chadian standard, except for pH, which is below the standard in seven (07) boreholes, four (4) boreholes have an iron concentration above the standard, and one borehole has a turbidity level;
- The results of the chemical analyses on the Piper diagram show that the dominant chemical facies is calcium-magnesium bicarbonate;
- Bacteriological analysis showed that all samples were contaminated with faecal germs: *Escherichia coli*, total coliforms and total aerobic flora;
- Bacteriological results show that all water analysed is highly contaminated;
- All analyses results carried out to the conclusion show that latrines have an effect on groundwater through the infiltration of wastewater at depth because distance required between latrines and water point was not respected.

Recommendations

According to our result, some actions should be taken to limit the degradation of water resources in the city of N'Djamena, specifically in the 5th district. we recommend to governments and NGOs wishing to drill ensure:

- Compliance with drilling standards, as well as compliance with the protection perimeters of the structures;
- On the technical level, drilling must be carried out by technicians who will take into account all the protective equipment against possible pollution such as the sealing gasket;
- The depth should be around 40 m to minimize the risk of pollution;
- The application of judicial measures to control the drilling of boreholes in order to avoid depletion of the resource or anthropogenic pollution of it due to the strong enthusiasm of the populations for this resource;
- Raising awareness among the populations on the construction of autonomous sanitation systems (sumps, latrines) on the one hand and domestic wells on the other hand in compliance with standards;
- Finally, the authorities should focus on information and awareness-raising regarding hygiene and sanitation in order to reduce the rate of waterborne diseases.

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Conflicts of Interest

The authors declare that there is no conflict of interest. This work is the part of the master's degree of the second author.

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