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Research Article

Hydrochemical and Bacteriological Characterization of Drinking Water in N'Djamena: A Case Study of the 2nd District

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Abstract

Access to drinking water is a major concern in the locality of least developing countries. Population growth and the demands of modern life require an increase in water production in both quantity and quality. This study aims to determine the physicochemical and microbiological quality of water from boreholes intended for human consumption in the 2nd district of N'Djamena, Chad. The methods used to solve the problem are based on physicochemical and microbiological analyses, the Piper diagram interpretation, and multivariate statistical analysis to determine the quality and classification of the water. The results show that the water has low mineralization with a Total Dissolved Solid (TDS) concentration of 141.2 ± 26.61 mg/L and an average electrical conductivity of 282.4 ± 53.58 µS/cm. And then, determination of the facies of the waters studied shows that they are of the calcium-magnesium bicarbonate type. The highest concentrations are those of Ca^{2+} (38.3 ± 7.79 mg/L) and HCO_3^- (189.76 ± 17.36 mg/L), and the lowest are K^+ (3.06 ± 0.63 mg/L) and NO_3^- (5.76 ±9.43 mg/L). The water contains fecal coliforms such as Escherichia coli, total coliforms, and Total Aerobic Mesophilic Flora. Due to the presence of these pathogenic germs, this water requires prior treatment before being used for human consumption.

Keywords

Physicochemical, Bacteriological, Drinking Water, N'Djamena

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1. Introduction

Water is an indispensable resource for sustaining human life as well as ecosystems [1]. Population growth coupled with socio-economic development is the basis for the increased demand for water, leading to the overuse of this resource [2, 3]. This is due to large-scale production and the discharge of significant volumes of wastewater into receiving environments [4, 5]. With various sources of water quality deterioration, preserving its quality becomes an important concern for any society seeking to meet its drinking water needs [6]. In this context, the United Nations (UN) advocates for access to water and sanitation for all and recommends sustainable management of this resource [7]. However, [8] reveal that one-third of the world's population does not have access to a source of drinking water, with half of this population located in Africa. Therefore, water resource management is a major issue in arid or semi-arid climates in Africa, as it contributes to the development of human, economic, and social activities.

Drinking water can contain a multitude of chemical and microbial constituents that can have detrimental effects on human health [9]. Physicochemical and bacteriological properties are therefore essential to assess the quality of drinking water [10, 11]. The harmful effects of chemical elements and bacterial colonies are mostly dependent on their concentration and number, respectively, for chemistry and bacteriology. However, population and economic growth in urban areas is the cause of environmental pollution, including surface and groundwater pollution. This phenomenon is observed in developing countries that are less concerned with the problem of discharging untreated or poorly treated wastewater, which generates groundwater and surface water pollution through infiltration and runoff [5, 12, 13].

In recent years, the city of N'Djamena has experienced population growth and significant urban expansion. However, the supply of drinking water has remained limited in certain areas, forcing city residents to obtain water from wells or boreholes that may be contaminated. Nevertheless, the uncontrolled proliferation of boreholes is also perceived as a threat, with the main impacts being pressure on groundwater resources [14] and public health risks for consumers [11, 15]. Studies conducted on the waters of the Chari River reveal that the values of the physicochemical parameters of these waters generally exceed WHO recommendations [16]. However, the work of [17] shows that the groundwater in the city of N'Djamena is fed partly by the waters of the Chari River and partly by rainwater. This can therefore be a source of contamination of the city's groundwater. The work of [18] conducted in the city of N'Djamena also showed that, in addition to these probable sources of contamination, the water chemistry of the area is controlled by the hydrolysis of silicates, the cation exchange between groundwater and clay minerals, and anthropogenic activities.

The objective of this study is to determine the physicochemical and microbiological quality of drinking water collected from boreholes located in the district locality of N'Djamena using hydro chemical and multivariate statistical methods.

2. Materials and Methods

2.1. Study Area

N'Djamena, the political capital of Chad, is located between 12.002° and 12.286° North latitude and between 14.848° and 15.287° East longitude. It lies in a semi-arid zone, characterized by a long dry season (October to May) and a short rainy season (June to September). The average annual rainfall is 584 mm, while temperatures range between 28℃ and 47℃ [19]. The city's waters are drained by the Chari and Logone rivers, which belong to the Lake Chad basin. N'Djamena is built on heterogeneous formations that include, from top to bottom: clayey-silty levels with sandy layers between 0 and 10 meters; a succession of sandy, clayey-sandy layers with clay lenses between 10 and 60 meters; and impermeable clays between 60 and 75 meters [20]. The impermeable to semi-permeable clay levels form the walls of the aquifers [21].

2.2. Sampling

Water samples were collected in August, September, and October 2022 from five boreholes located in the 2nd district of N'Djamena. Three samples were taken from each borehole. The water was collected in polyethylene bottles for chemical analysis after being filtered with 0.45 µm cellulose filters, and in glass bottles for bacteriological analysis. The bottle containing water for cation analysis was acidified to prevent precipitation. The samples were sealed and kept at 4℃ in a cooler with ice packs for transportation to the National Water Laboratory of N'Djamena.

2.3. Physiochemical and Bacteriological Analysis

Physical parameters such as temperature, pH, and conductivity were determined in situ at each sampling using a Hanna HI 98130 multi-parameter probe. The concentrations of Fe^{2+}, NO_3^-, SO_4^{2-}, and NH_4^+ ions were measured by atomic absorption spectrophotometry using a HACH DR/3900 spectrophotometer. The ion concentrations in mg/L of each sample were read after the "blank" by inserting the tubes into the device each time. Na^+ and K^+ ions were measured by flame photometry using a BWB-XP flame emission spectrophotometer. The measurements were taken at wavelengths of 589 and 768 nm for sodium and potassium, respectively. Cl^- ions were measured by titrimetry. Ca^{2+}, Mg^{2+}, and HCO_3^- were determined by volumetric titration.

For bacteriology, the membrane filtration method was used to count the bacteria present in the water. This method involves filtering a volume of 100 mL of the sample water through a 0.45 µm pore size millipore membrane [22]. The analyses focused on the enumeration of Escherichia coli, total coliforms, fecal enterococci, and Total Aerobic Mesophilic Flora. The determination of these parameters was done according to the [23] protocol. The media used were as follows: chromocult agar for E. coli and total coliforms; Slanetz and Bartley medium for fecal enterococci; and PCA for total aerobic mesophilic flora.

2.4. Data Processing

The results of the cation (Ca^{2+}, Mg^{2+}, (Na^{+} + K^{+})) and anion (HCO_3^-, SO_4^{2-}, and (Cl^- + NO_3^-)) analyses were plotted on Piper hydrochemical diagrams [24] to study the geochemical processes underlying water mineralization. The results of the hydrochemical parameters, including pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, and Fe^{2+}, were used to perform a principal component analysis (PCA). PCA is used in hydrogeochemistry by many authors [25, 26] as a multivariate statistical technique that transforms a large number of variables into a smaller number of factors to detect and identify groups of well-correlated variables. XLStat software (version 2018) was used for statistical analyses.

3. Results

3.1. Physicochemical Quality of Water

The results of the physicochemical analyses of the studied waters are presented in Table 1. The temperature of these waters ranges from 29.1 to 31 ℃, with an average of 29.85 ℃ and a standard deviation of 0.71. The pH ranges from 6.4 to 7.2 with an average of 6.94. The pH of the waters in the study area falls within the range determined by [9] for drinking water. The values of electrical conductivity range from 219 to 366 µS/cm, with an average of 282.4 µS/cm and a standard deviation of 53.58, indicating a significant variation in this parameter. The waters in the 2nd district of N'Djamena are weakly mineralized, with TDS values ranging from 110 to 183 mg/L, an average of 141.2 mg/L, a standard deviation of 26.61, and a CV of 18.85. The highest mineralization is found in borehole F4, which has the highest EC (366 µS/cm) and the highest pH (7.2).

Table 1. *Results of physicochemical and bacteriological analyses of water and descriptive statistical analysis of data.*

	WHO (2004)	F1	F2	F3	F4	*F5*	Min	Max	Average	S-D	CV
T ℃		29,46	29,1	29,9	31	*29,8*	29,1	31	29,85	0,71	2,39
pH	6,5–8,5	7,1	6,40	6,97	7,20	7,05	6,4	7,2	6,94	0,32	4,54
EC *(µS/cm)*	≤500	280	219,0	286,0	366,0	261,0	219	366	282,4	53,58	18,97
TDS *(mg/L)*	500	139	110,0	143,0	183,0	131,0	110	183	141,2	26,61	18,85
Ca^{2+} *(mg/L)*	≤100	45	28,5	40,0	46,0	32,0	28,5	46	38,3	7,79	20,34
Mg^{2+} *(mg/L)*	≤150	12,3	11,3	14,6	14,6	14,6	11,3	14,6	13,48	1,57	11,68
K^{+} *(mg/L)*	≤200	3,2	2,4	2,4	3,6	3,7	2,4	3,7	3,06	0,63	20,62
Na^{+} *(mg/L)*	≤200	14,2	8,6	11,3	17,4	12,0	8,6	17,4	12,7	3,30	26,00
NH_4^{+} *(mg/L)*	≤0,5	0,206	1,01	0,77	0,77	0,54	0,2	1,01	0,66	0,30	45,96
Cl^- *(mg/L)*	<200	10,8	5,0	19,0	16,0	10,0	5	19	12,16	5,46	44,91
SO_4^{2-} *(mg/L)*	<250	2	1,0	5,0	3,0	2,0	1	5	2,6	1,52	58,33
NO_3^- *(mg/L)*	<50	7,1	0,0	0,0	21,7	0,0	0	21,7	5,76	9,43	163,65
HCO_3^- *(mg/L)*		198,7	168,4	195,2	210,8	175,7	168,4	210,8	189,76	17,36	9,15
Fe^{2+} *(mg/L)*		0,01	0,0	0,0	0,5	0,0	0	0,5	0,102	0,22	218,17
E. Coli (ufc/100 ml)		0	0	0	18	0	0	18	3,6	8,05	223,61
TCB (ufc/100 ml)		33	0	0	9	0	0	33	8,4	14,29	170,16
FE (ufc/100 ml)		1	0	0	0	0	0	1	0,2	0,45	223,61
TAMF (ufc/100 ml)		>100	>100	>100	>100	>100					

The concentrations of Ca^{2+} range from 28.5 to 46 mg/L, with an average of 38.3 mg/L. These concentrations show a remarkable variation from one sampling point to another, as indicated by a standard deviation of 7.79 and a high CV (20.34). In contrast, the concentration of Mg^{2+} ions in the area ranges from 11.3 to 14.6 mg/L. The average concentration of Mg^{2+} ions is 13.48 mg/L, indicating a low variation with a standard deviation of 1.57. The Na^{+} concentrations in the studied waters range from 8.6 to 17.4 mg/L, with an average of 12.7 mg/L, a standard deviation of 3.3 mg/L, and a CV of 26. The K^{+} concentrations are relatively low, ranging from 2.4 to 3.7 mg/L, with an average of 3.06 mg/L, a standard deviation of 0.63, and a high CV of 20.62.

The Cl^{-} concentrations range from 5 to 19 mg/L, with an average concentration of 12.16 mg/L. The distribution of concentrations varies significantly from one sample to another, as indicated by a standard deviation of 5.46 and a CV of 44.91. The NO_3^{-} ions are present in low concentrations, ranging from 0 to 21.7 mg/L, with an average of 5.76 mg/L. The contribution of each point to NO_3^{-} mineralization varies, as indicated by a standard deviation of 9.43 and a CV of 163.65. The SO_4^{2-} analysis results show values ranging from 1 to 5 mg/L, with an average of 2.6 mg/L and a standard deviation of 1.52. The HCO_3^{-} concentrations in the studied waters range from 168.4 to 210.8 mg/L, with an average of 189.76 mg/L. These concentrations fluctuate significantly, with a high standard deviation of 17.36 and a CV of 9.15.

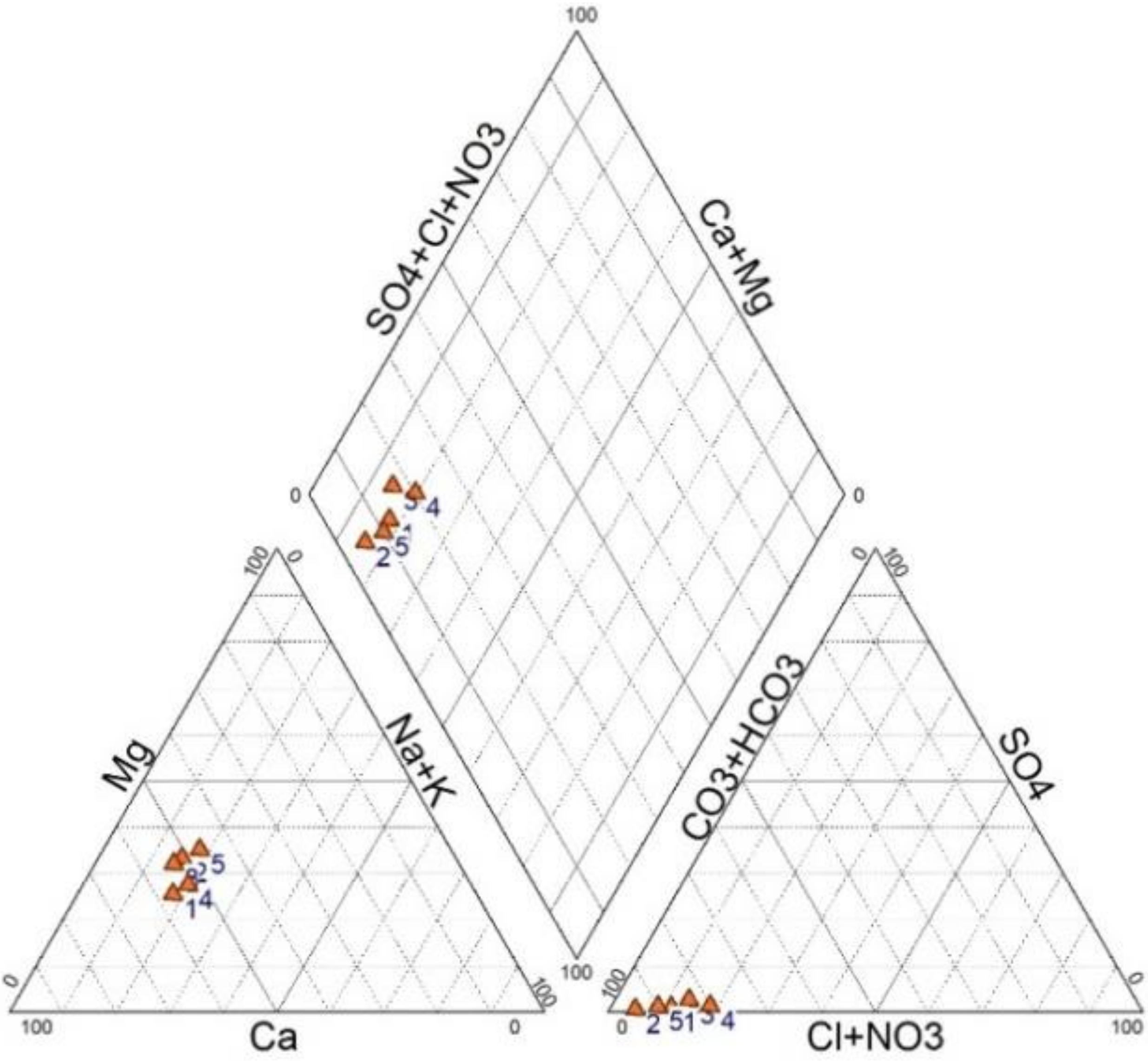

Figure 1. *Piper diagram showing the chemical characteristics of water analysis.*

The results of the physicochemical analyses of the major ions in the waters of the study area were plotted on the Piper diagram (Figure 1) to highlight their hydro chemical classification. This classification facilitates their interpretation to better understand the chemical differences and similarities between the water samples. Overall, the studied water samples have the same facies, the bicarbonate-calcium-magnesium facies. The waters are mainly enriched in calcium for cations and bicarbonates for anions. The order of importance in terms of the representativeness of the major ions in the studied waters is as follows: Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} for cations, and HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- for anions.

3.2. Bacteriological Analysis

The results of the microbiological analyses are presented in Table 1. These results indicate that none of the analyzed samples are free from the targeted germs. However, samples F2 and F3 contain only Total Aerobic Mesophilic Flora (TAMF). While TAMF is present in all samples, Total Coliforms (TCB) are only found in the waters of boreholes F1 and F4, Fecal Enterococci (FE) in sample F1, and Escherichia coli (EC) in F4.

3.3. Correlation Study and Principal Component Analysis

Tables 2 and 3 present the results of the Principal Component Analysis (PCA). The eigenvalues, the variances expressed for each factor, and their cumulative values are listed in Table 3. The most important factor, with an expressed variance of 63.64%, is factor F1, followed by factors F2 and F3, which express 16.16% and 12.45% of the variance, respectively. Table 2 highlights the significant correlations that exist between the different parameters.

The analysis of the correlation circle of variables F1-F2 (Figure 2) and the graphical representation of the factorial map F1-F2 (Figure 3) show that the studied variables define three groupings representing three classes. Class 1, formed by elements correlated with F1, shows an affinity between the variables Na^{+}, Ca^{2+}, Mg^{2+}, NO_3^-, HCO_3^-, and Fe^{2+}. Class 2 is built around SO_4^{2-} and a negative correlation of K^{+} with F2. The third group is represented by NH_4^+ ions.

Table 2. correlation matrix between the different variable taken pairwise.

Variables	pH	EC	TDS	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	NH_4^+	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-	Fe^{2+}
pH	1												
EC	0,789	1											
TDS	0,783	1,000	1										
Ca^{2+}	0,786	0,832	0,820	1									
Mg^{2+}	0,724	0,637	0,645	0,345	1								
K^{+}	0,716	0,522	0,523	0,326	0,467	1							
Na^{+}	0,854	0,932	0,927	0,860	0,485	0,712	1						
NH_4^+	-0,636	-0,138	-0,121	-0,496	-0,060	-0,503	-0,417	1					
Cl^-	0,670	0,725	0,725	0,681	0,778	0,052	0,517	-0,069	1				
SO_4^{2-}	0,459	0,485	0,486	0,478	0,698	-0,204	0,230	0,050	0,951	1			
NO_3^-	0,560	0,889	0,888	0,731	0,268	0,534	0,905	-0,071	0,358	0,077	1		
HCO_3^-	0,779	0,917	0,909	0,978	0,457	0,322	0,881	-0,330	0,762	0,557	0,794	1	
Fe^{2+}	0,462	0,876	0,881	0,565	0,391	0,483	0,805	0,189	0,392	0,144	0,951	0,686	1

Table 3. Eigen values and expressed percentage for the principal axes.

	F1	F2	F3	F4
Eigenvalue	8,273	2,102	1,619	1,006
Variability (%)	63,642	16,168	12,454	7,737
% cumulative	63,642	79,810	92,263	100,000

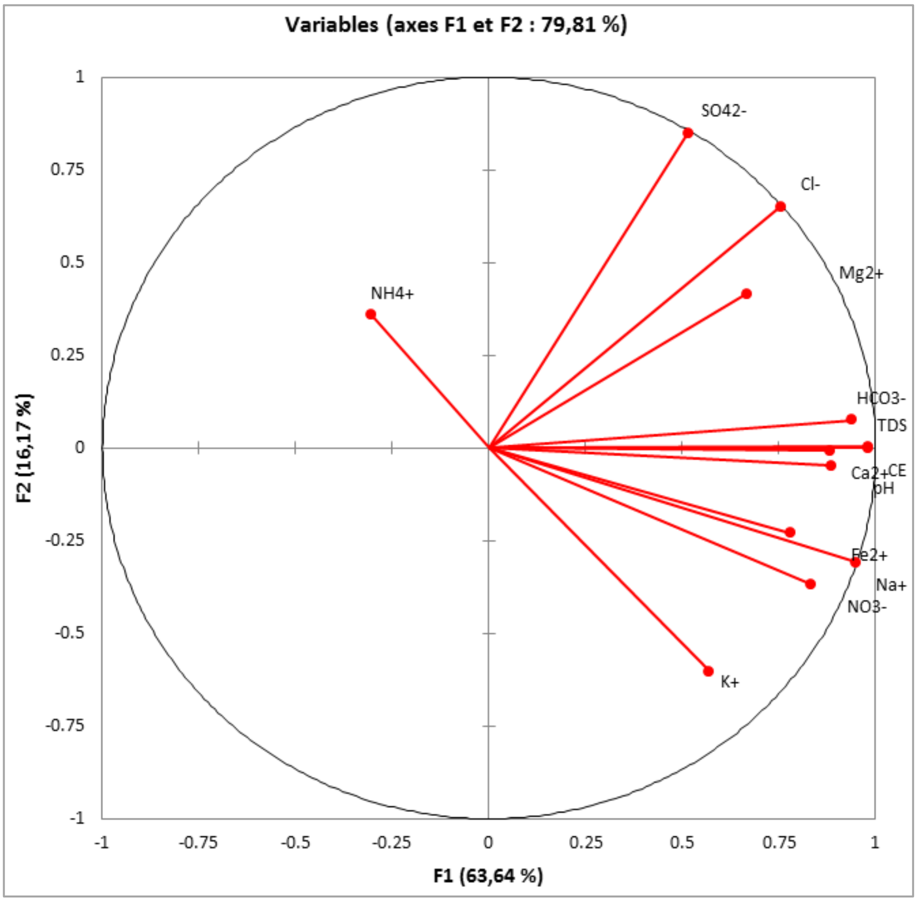

Figure 2. Correlation circle plot of F1-F2.

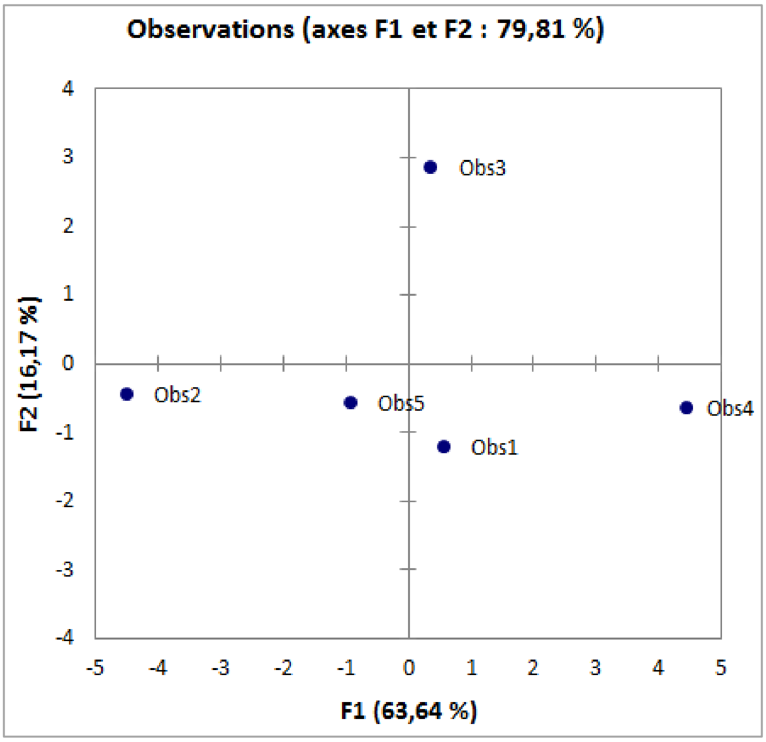

Figure 3. Graphical representation of the factorial map of wells.

4. Discussion

The pH of the water ranges from 6.4 to 7.2, with an average of 6.94. These values fall within the range recommended by the [9] for drinking water. These pH values are consistent with those obtained by [27] in their study of water distributed by the Soci été Tchadienne des Eaux in N'Djamena. Conductivity measurement allows for the evaluation of ion movement in water, thus indicating its overall mineralization [22]. The conductivity values of the studied waters are heterogeneous, with a standard deviation of 53.58 and a CV of 18.97. These variations could indicate that there are various sources of groundwater mineralization in the study area. TDS shows less variation than EC, with a standard deviation of 26.61 but a CV approximately equal (18.85) to that of EC. Several mechanisms underlie the variation in TDS, including evaporation, the dissolution of evaporites, and ion exchange with the surrounding rock, as demonstrated by [28].

The major cations generally have low values compared to [9] standards. Calcium concentrations range from 28.5 to 46 mg/L, with an average of 38.3 ± 7.27 mg/L. The average calcium concentrations likely result from the dissolution of gypsum formations ($CaSO_4$, $2H_2O$), which are easily soluble in water [29]. These calcium concentrations are well below the [9] limits. Magnesium concentrations average 13.48 ± 1.57 mg/L. The presence of these ions in the studied waters may result from ion exchange processes involving alkaline earth metals and the dissolution of evaporites rich in magnesium. The low coefficient of variation (11.68%) indicates that the sources of input are less diversified. Potassium concentrations range from 2.4 to 3.7 mg/L, with an average of 3.06 ± 0.63 mg/L. These concentrations are far below the [9] recommendations for drinking water, which state that potassium concentrations should be below 200 mg/L. Sodium significantly contributes to the mineralization of these waters, considering its concentration in samples with high TDS. [30] highlighted that sodium in water can result from ion exchange, accumulation, and the dissolution of evaporites. Ammonium ions are present in concentrations slightly above the [9] recommendations for drinking water, which is 0.5 mg/L.

Anions also contribute minimally to the mineralization of the waters in the study area. Bicarbonates are the ions with the highest concentration, averaging 189.76 ± 17.36 mg/L. The coefficient of variation for these ions is low (9.15) compared to other anions. Bicarbonates in water result from the hydrolysis of silicate minerals present in the rock under the influence of CO_2 in the water, following the decomposition of organic matter in the upper soil layers, as reported by [31]. Chlorides are present in low concentrations in the waters of the area, with average concentrations of 12.16 ± 5.46 mg/L. Evaporation is likely the source of chlorides in these waters, as these ions tend to concentrate in evaporating waters. Sulfates, with very low average concentrations (2.6 ±1.52 mg/L), contribute little to the mineralization of the studied waters. The presence of sulfate ions in water primarily results from the dissolution of gypsum formations [32]. The dissolution reaction rate cannot be uniform across all points of the aquifer, leading to significant variations in concentrations from one sample to another; this is justified by the high CV of 58.33%, indicating a heterogeneous distribution around the average ionic concentration [33]. Nitrate concentrations remain low, with an average of 5.76 mg/L. The absence of this ion in samples F2, F3, and F5 explains the high standard deviation and coefficient of variation, which are 9.43 and 163.65%, respectively.

In summary, calcium and bicarbonates are the most abundant ions in the waters. The order of importance of the major ions and the facies of these waters, as represented in Figure 1, are consistent with the results of [34] conducted in the aquifers of N'Djamena.

The study of the bacteriological quality of the waters in the 2nd district of N'Djamena focused on the detection and enumeration of Escherichia coli (E. coli), total coliforms (TCB), fecal enterococci (FE), and Total Aerobic Mesophilic Flora (TAMF). The presence of these pathogenic germs indicates water pollution. Indicator germs of pollution, such as E. coli, show fecal contamination of the waters, as reported by [35] in their study in Yaound é, Cameroon. The [9] recommends the total absence of pathogenic germs in drinking water; however, in our case, these germs (E. coli, TCB, TAMF) are present.

Principal Component Analysis (PCA) provides information contained in the physicochemical analysis data, either in the form of data tables or graphs [36]. The correlation matrix in Table 2 shows the relationship between variables taken two by two. This table shows that TDS is strongly correlated with sodium, nitrates, bicarbonates, and iron. The correlation data for TDS with chemical elements are as follows: Na^+ (0.92), NO_3^- (0.88), HCO_3^- (0.90), and Fe^{2+} (0.88). Bicarbonates, major elements of the studied waters, are strongly linked to alkaline earth metals (Ca^{2+}) and an alkali metal (Na^+). The correlation between Ca^{2+} and Mg^{2+} is very low (0.34), indicating a significant contribution from infiltration waters, limiting the residence time of water in the aquifer to allow the dissolution of mineral elements contained in the aquifer rock, as demonstrated by [37].

Table 3 shows that the first two axes alone account for 79.81% of the total variance, with axis 1 explaining 63.64% and axis 2 explaining 16.17% of this variance. Axis 1 is positively correlated with HCO_3^-, Na^+, and Ca^{2+}. This axis expresses the mineralization of the water in the area, considering the strong correlation between these chemical parameters and TDS. A correlation of TDS with the major ions present in the water defines mineralization through the hydrolysis of minerals [38]. In contrast, axis 2 is correlated with SO_4^{2-}. NH_4^+, correlated with a third axis (Figure 2), indicates a contribution to mineralization through incomplete decomposition of organic matter, as well as through the biodegradation of waste, leading to the reduction of organic nitrogen [39].

5. Conclusion

The study of the physico-chemical and microbiological characteristics of the waters in the 2nd district of N'Djamena has provided insight into the quality of these waters and the processes influencing their mineralization and bacteriological contamination. The physico-chemical analyses of the waters in the area show that they are weakly mineralized, with an average TDS of 141.2 ± 26.61 mg/L. Calcium and bicarbonates are the ions that predominantly contribute to the mineralization of these waters. The hydrochemical facies encountered is of the bicarbonate-calcium-magnesium type. The microbiological analyses show that the analyzed waters contain fecal coliforms such as Escherichia coli, Total Coliforms, and Total Aerobic Mesophilic Flora. These waters are of average quality and are therefore recommended for human consumption after prior treatment.

Abbreviations

CV	Correlation of Variation
PCA	Principal Component Analysis
SD	Standard deviation
TDS	Total Dissolved Solid
WHO	World Health Organization

Author Contributions

Aguiza Abai Emmanuel: Conceptualization, Methodology, Project administration, Resources, Writing – original draft, Writing – review and editing

Baba Ahmadou: Data curation, Project administration, Resources, Software, Visualization

Diab Ahmad Diab: Formal Analysis, Investigation, Resource, Visualization

Ilyass Ali Oumar: Data curation, Project administration, Software, Visualization

Domra Kana Janvier: Data curation, Validation, Visualization, Writing – original draft, Writing -review and editing

Conflicts of Interest

The authors declare no conflicts of interest.

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