Article

Analysis and Control of the Physicochemical Quality of Groundwater in the Chari Baguirmi Region in Chad

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Abstract: Water resources are threatened nowadays by pollution that comes from domestic, industrial and agricultural discharges without prior treatment. This pollution causes the degradation of water quality. Surface pollutants can seep through the soil into water tables. The objective of our work is to assess and control the physicochemical quality of the Chari Baguirmi groundwater, to protect human health. The quality of 83 boreholes was assessed, while performing analysis for 12 physicochemical parameters at the National Water Laboratory and at the Center for Quality Control of Foodstuffs in Chad. These parameters are: pH, EC, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NH_4^+ and NO_3^-, Fe^{2+} and HCO_3^-. Also, the results obtained were compared with WHO standards. The geochemical statistical approach has made it possible to characterize the hydro geochemical properties and to understand the major processes of the mineralization of groundwater resources in Chari Baguirmi region in Chad. Some of its waters are acidic and weakly mineralized, rich in Fe^{2+} and NH_4^+. The origin of the mineralization is due to the alteration of the host rocks and to the hydrolysis of silicate and ferromagnesian minerals as well as anthropogenic pollution. The ammonium concentrations in N'Djamena boreholes are higher than WHO standards, indicating the presence of pollution which may come from organic waste. These results constitute a preliminary step in understanding hydro geochemical functioning and a basis for monitoring the physicochemical quality of the water in the study area.

Keywords: Analysis; control; physicochemical quality; groundwater; Chari Baguirmi region; Chad

1. Introduction

Water is necessary for all forms of life. It is an element for promoting the health of individuals and socio-economic development of human communities [1].

Without this simple yet complex material, life on earth would never have existed so it is a noble crucial element that we must be protected for future generations. Water intended for human consumption is drinkable when it is free from chemical and biological elements. According to WHO [2], 1.8 million people a year, 90% of whom are children under five , mostly living in developing countries, die from diarrheal diseases (including cholera); 88% of diarrheal illnesses are caused by poor water quality, poor sanitation and poor hygiene.

The deterioration of the water quality in aquatic ecosystems is an increasingly important issue in Chad as elsewhere in the world and particularly in the Sub-Saharan context where water resources are limited and remain fragile and threatened.

In Chad, water is used primarily in whole process of manufacturing food and other products. The agro-food industries of Sarh, Ndjamena and Moundou use different sources of water, but public water mains and wells are the principle sources of water used by the population. This water can prove to be the main source of possible contamination and alteration of food.

Our goal is to assess the physicochemical quality of the drilling water used in the Chari Baguirmi region in Chad and to identify the various chemicals responsible for the pollution of these waters and to define the main causes of this pollution.

2. Materials and Methods

2.1. Study Area

Our study area Chari-Baguirmi region is divided into three departments: Baguirmi (city center of Massenya), Chari (city center of Mandelia) and Loug Chari (city center of Bousso). As a part of decentralization in February 2003. It covers an area of 17,761 Km², with a population estimated at 621,785 inhabitants [3]. This study area covers the localities of N'Djamena center and its surroundings, Klessoum, Bousso, Ba-illi, Massenya, and Dourbali.
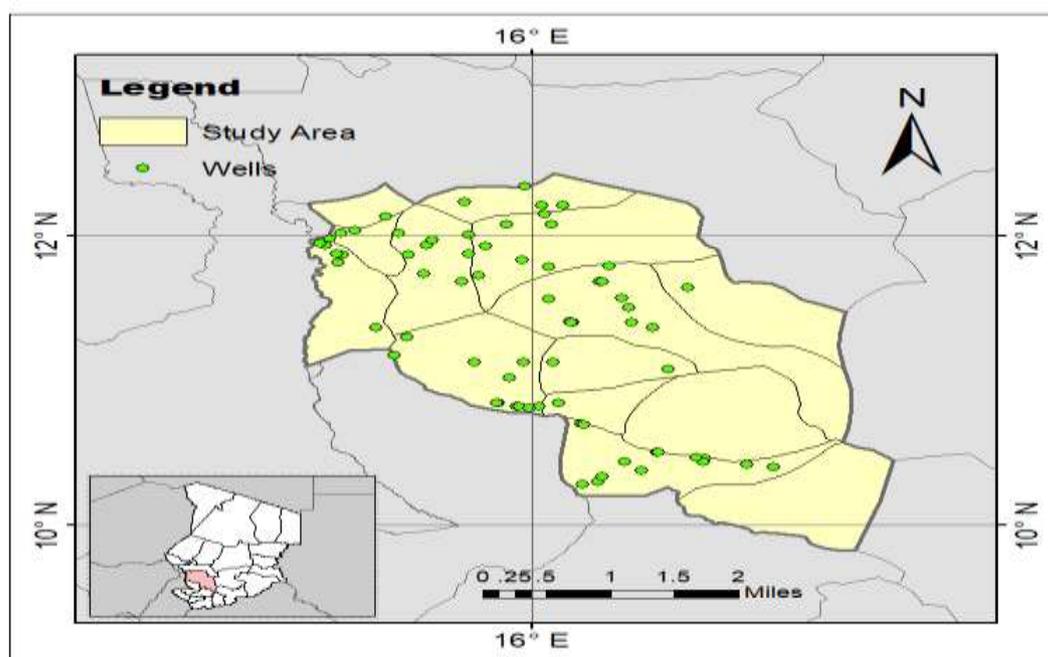

Figure 1. Study area.

2.2. Analysis Methods

We determined our physical and chemical parameters in the field (in situ) and in the laboratories according to the technic of Rodier [4].

- **In situ measurements**

The measurements carried out in the field concern the physical parameters: temperature (T°C), hydrogen potential (pH) and electrical conductivity (EC). They were taken immediately after taking the water samples, using two portable devices: the WTW pH 330 pH meter (with a precision of 0.01 pH units) and the WTW315i conductivity meter (with a precision of ± 1digit).

- **Laboratory analyzes**

Several analytical methods were used: Colorimetric assay methods have made it possible to determine nitrates (NO_3^-), sulphates (SO_4^{2-}), total iron (Fe^{2+}), potassium (K^+), from the DR 2400

spectrophotometer (precision ± 1nm). The volumetric EDTA method was used to measure calcium (Ca^{2+}), magnesium (Mg^{2+}) and determine the total duration of the water, using the digital titrator. It was also used to measure chlorides (Cl^-), silver nitrate and bicarbonates (HCO_3-) with acid 0.1 N hydrochloric acid from the digital titrator. Sodium (Na^+) was determined by flame atomic absorption spectrophotometry and Ion selective electrode (ISE) for the measurement of ammonium (NH_4^+).

- **Data processing**

The results of the physicochemical analyzes were processed by multivariate statistical analysis methods coupled with hydro chemical methods. The hydro chemical method required the use of the Piper diagram produced under the Diagrams software, for the hydro chemical classification of water. This diagram is widely used in hydrochemistry and gives satisfactory results. The statistical approach is based on the use of Normalized Principal Component Analysis (SNA) and Ascending Hierarchical Classification (CHA) to study the phenomena at the origin of water mineralization, water pooling and identify the factors responsible for these groupings. Both of these statistical methods are commonly used in water science. The statistical analyzes were carried out using the XLSTAT 2011 software.

The values of the parameters were compared to the standards of the World Health Organization [5] for drinking water.

3. Results

The results of the physicochemical analyzes carried out are represented by the graphs and the table below. The WHO and European Union drinking water quality standards were used as the basis for the interpretation of our results.

Table 1. Values of the physicochemical parameters of the drilling water analyzed.

No	Stations	Conductivity	pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe^{2+}	NH_4^+	NO_3^-	HCO_3^-	Cl^-	SO_4^{2-}
1	TOURLI 1	90	6.3	30.4	4.4	30.0	5.0	0.02	0.05	9.0	114.7	26.0	25.0
2	MASSENYA	102	6.4	22.4	1.9	24.0	3.0	0.06	0.15	7.0	78.1	21.0	17.0
3	MASSENYA	159	6.96	20.8	1.5	21.0	2.7	0.0	0.05	8.0	70.8	19.0	15.0
4	MASSENYA	417	7.42	20.0	1.0	19.0	2.4	0.1	0.05	7.0	65.9	17.0	13.0
5	NDJAMENA	126	6.11	6.4	1.9	10.0	1.6	0.2	0.13	5.0	29.3	10.1	5.0
6	NDJAMENA	219	6.4	28.0	3.4	27.0	4.0	0.1	0.24	7.0	102.5	24.0	22.0
7	NDJAMENA	22	6.76	24.0	3.9	25.0	3.7	0.1	0.02	9.0	92.7	20.0	19.0
8	NDJAMENA	261	7.06	7.2	2.4	12.0	1.8	0.0	0.03	8.0	34.2	11.0	6.0
9	NDJAMENA	286	6.97	5.6	1.5	8.0	1.2	0.3	0.40	2.0	24.4	8.0	4.0
10	KLESSOUM	212	7.53	17.6	1.0	17.0	2.1	0.1	0.00	8.0	58.6	14.0	11.0
11	KARNAK	198	6.87	11.47	2.82	3.19	3.41	0.0	3.00	0.7	173.91	0.94	0.34
12	MASSENYA Q LA PAIX	181	6.53	38.63	10.17	15.18	4.73	0.0	1.81	21.8	120.8	54.51	10.49
13	TOURLI	96	6.48	9.38	2.88	2.8	3.41	0.0	0.32	0.8	56.13	1.25	0.51
14	ABOUSSAKINE	323	6.5	24.73	6.81	13.73	5.19	0.0	1.63	5.3	156.82	4.6	6.38
15	BALABOUDA	278	6.61	22.43	6.48	13.69	5.28	0.0	1.60	2.8	144.04	2.8	5.55
16	NDJAMENA	198	6.6	22.55	6.12	8.36	4.53	0.0	1.05	7.2	173.9	8.13	4.62
17	NDJAMENA	342	6.5	23.83	6.77	14.28	5.32	0.0	1.70	3.9	143.4	4.42	0.26
18	NDJAMENA	333	6.47	22.15	6.51	13.58	5.28	0.0	1.61	2.1	140.95	2.91	5.52
19	NDJAMENA	515	6.45	8.18	2.38	2.8	2.71	0.0	0.83	0.0	53.7	0.65	0.35
20	NDJAMENA	375	7.08	8.18	2.38	2.8	2.71	0.0	0.83	0.0	53.7	0.65	0.35
21	NDJAMENA	180	6.65	24	13.6	3	0.8	0.0	1.31	0.0	74	5	4
22	NDJAMENA	366	7.2	25.6	1.2	8.6	2.4	0.0	1.01	0.0	175	5	1
23	NDJAMENA	461	6.55	4.8	18	2	0.4	0.0	0.24	0.0	59	2	0
24	NDJAMENA	590	6.6	32	14.6	12	3.7	0.0	0.54	0.0	233	10	2
25	NDJAMENA	435	6.25	40	14.6	28.3	2.4	0.0	0.77	0.0	255	19	30
26	NDJAMENA	758	6.92	26.4	15.6	5.7	2.8	0.0	0.26	0.0	239	10	15
27	NDJAMENA	231	7.13	40	19.4	17.01	3.6	0.0	0.74	8.9	248	20	7
28	NDJAMENA	92	6.9	44.8	21.4	16.8	3.7	0.2	0.75	0.0	392	17	11
29	NDJAMENA	195	7.04	42.4	19	17.3	3.7	0.0	0.66	0.0	137	10	7
30	NDJAMENA	208	6.99	45.6	35.5	27.3	4.5	0.0	1.13	0.0	143	19	18
31	NDJAMENA	402.66	6.9	36	7.3	6.3	2.8	0.1	1.07	0	127	14	2
32	NDJAMENA	146.1	7.36	47.2	10.2	23.8	3.8	0.1	0.8	1.2	128	12	3
33	NDJAMENA	384	6.7	36	9.2	3.7	1.8	0.5	5.14	1.2	300	11	6
34	NDJAMENA	327.33	7.2	32	14.6	31.6	3.6	0.6	0.77	21.7	192	32	12
35	NDJAMENA	146.1	7.36	20	7.3	28.4	2.6	0.1	0.48	0	159	10	2

36	NDJAMENA	384	6.7	49.6	20.4	25.1	5.1	0.2	1.17	0	162	10	7
37	NDJAMENA	687.6	6.5	90.4	25.3	9.1	6	0.1	0.7	0	209	7	1
38	NDJAMENA	270.66	6.7	60	1.2	9.5	4.3	0.1	0.88	0	310	10	10
39	NDJAMENA	254	7.5	58.4	20.9	10.7	4.9	0.1	1.23	0	127	14	0
40	NDJAMENA	120.33	7.5	68	30.6	8.6	2	0.2	0.01	24.9	299	30	13
41	NDJAMENA	461	7.6	64	29.2	44.9	7.5	0.1	0.55	4.4	143	40	42
42	NDJAMENA	644.33	7.4	44	2.4	22	2.3	0.1	0.73	5.5	133	15	0
43	BOUSSO	309	7.3	16	5.3	13.5	3.2	0.0	0.41	6.0	87.8	7.0	5.0
44	BOUSSO	77.15	7.5	2.4	1.0	7.1	1.0	0.0	0.33	4.0	24.4	2.0	0.0
45	BOUSSO	210	7.3	88	19.4	89.0	6.0	0.0	0.71	8.0	414.8	67.0	58.0
46	BOUSSO	197.7	7.3	3.2	1.9	8.0	1.5	0.0	0.29	4.4	31.7	4.0	0.0
47	BOUSSO	305	7	24.8	4.4	18.0	4.0	0.0	0.19	5.6	102.5	20.0	7.0
48	BOUSSO	209.5	7.3	3.2	1.5	7.6	1.3	0.0	0.41	3.0	29.3	3.0	0.0
49	BOUSSO	199.85	7.3	15.2	5.3	18.0	3.7	0.2	0.82	3.0	97.6	10.0	6.0
50	BOUSSO	68.9	7.6	3.2	1.5	4.7	0.5	0.2	0.66	2.0	17.1	5.0	0.0
51	BOUSSO	68.9	7.6	6.4	0.5	5.0	0.8	0.1	0.38	4.0	22.0	6.0	0.0
52	MASSENYA	247	6.57	40.35	7.9	9.08	7.65	0.0	2.74	17.1	175.73	14.78	1.94
53	MASSENYA	209	5.69	80.57	17.0	7.7	7.88	0.0	0.69	3.6	128.14	34.32	2.73
54	MASSENYA	198	6.27	28.09	5.8	7.48	3.51	0.0	1.20	13.6	433.24	7.38	1.62
55	MASSENYA	305	6.26	106.52	23.8	15.2	7.36	0.0	0.00	0.3	290.45	54.45	9.54
56	MASSENYA	205	5.93	37.12	8.8	14.49	4.46	0.0	2.02	0.0	162.92	22.64	6.33
57	MASSENYA	106	6.4	64.41	8.81	10.08	4.08	0.0	5.73	0.0	284.96	25.14	2.73
58	MASSENYA	969	6.53	31.3	14.8	19.75	5.66	0.0	1.11	0.3	192.82	19.56	13.62
59	MASSENYA	416	6.7	30.3	4.9	18.19	5.9	0.0	2.70	0.0	98.85	1.59	0.69
60	MASSENYA	315	7.23	12.2	7.1	6.16	4.32	0.0	0.85	24.4	175.13	1.59	0.69
61	MASSENYA	196	6.76	43.7	2.6	20.21	4.43	0.0	0.64	4.4	241.03	62.97	15.4
62	BA ILLI	110	5.66	1.6	1.0	2.0	0.8	0.2	0.47	5.6	7.3	2.0	8.6
63	BA ILLI	260	6.32	20.8	2.9	15.0	1.7	0.1	0.39	3.0	85.4	10.0	7.0
64	BA ILLI	143	5.26	4.8	1.0	6.3	0.7	1.3	0.39	6.0	19.5	7.0	1.0
65	BA ILLI	95	6.12	6.4	1.0	7.0	0.5	0.2	0.47	5.6	24.4	6.0	0.0
66	BA ILLI	210	6.32	20.8	2.9	15.0	1.7	0.0	0.64	8.0	85.4	10.0	7.0
67	BA ILLI	481	4.96	10.4	3.4	14.0	3.2	0.0	0.55	2.0	48.8	13.0	6.0
68	BA ILLI	478	4.81	4	2.1	4.0	0.4	0.1	0.39	3.0	19.0	6.6	0.0
69	BA ILLI	51.3	5.4	1.8	0.9	2.5	0.1	0.0	0.76	8.0	7.3	3.0	0.0
70	BA ILLI	196	6.53	10.4	3.4	1.7	0.9	0.0	0.66	6.0	34.2	7.0	0.0
71	BA ILLI	537	6.52	3.2	1.5	1.9	0.7	0.0	0.82	3.0	12.2	3.0	0.0
72	BA-ILLI	341	7	1.6	1.0	1.7	0.6	0.2	0.23	6.0	7.3	2.0	0.0
73	BA-ILLI	355	6.77	41.6	8.7	10.7	2.2	1.4	0.35	4.0	170.8	12.0	4.0
74	BA-ILLI	395	6.65	8.8	4.4	4.6	1.6	0.2	0.14	9.0	46.4	6.0	1.0
75	DOURBALI	498	6.8	43.7	0.47	40.25	3.53	0.0	1.25	11.0	148.8	5.88	6.62
76	DOURBALI	495.66	6.9	19.4	11.94	32.39	6.94	0.0	1.11	15.4	194.4	11.47	6.43
77	DOURBALI	499.33	6.8	12.1	4.34	24.15	5.48	0.3	0.71	4.4	168	5.29	8.72
78	DOURBALI	382.66	6.7	22.6	2.81	40.98	5.1	0.0	1.00	17.6	185	29.62	6.28
79	DOURBALI	198.5	6.8	11.1	3.32	6.12	5.1	0.0	0.88	0.0	127	10	14.77
80	DOURBALI	293	6.8	10.9	6.93	19.1	6.62	0.0	1.01	8.8	130	12.43	3.28
81	DOURBALI	216	6.7	17.4	4.68	11.21	4.68	0.0	0.10	2.2	169	4.71	0.12
82	DOURBALI	213.9	7	22.8	2.7	15.09	2.93	0.0	0.20	1.5	189	1.1	14.64
83	DOURBALI	265	6.9	34.0	6.5	23.86	5.6	0.0	1.11	13.5	144	14.82	1.48

The results of the physicochemical analysis presented in this work can be considered admissible, these results are in agreement with those obtained by Allahabo Ahmat Alhabo, [6] and Mahamat Seid Ali Malloum et al. [7].

- **Temperature**

During our sampling, the temperature values are higher, but we note that the temperatures also vary little from one point to another. The minimum value is 25.8 ° C and the maximum 33.1 ° C.

- **pH**

The pH represents the concentration of hydrogen ions in a solution and for natural waters the pH is linked to the nature of the terrain crossed. Certain pH values recorded do not exceed the maximum acceptable pH of the WHO which ranges from 6.5 to 8.5 for quality drinking water. These waters show notable variations and have tendency to be acidic with a minimum of 4.81
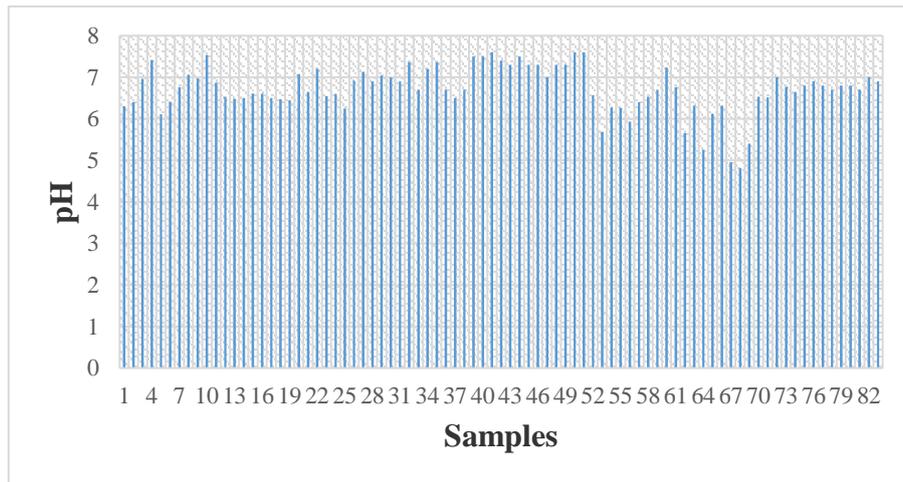
Figure 2. pH variation.

- **Conductivity**

The conductivity reflects the water mineralization; it varies according to the concentration of dissolved salts and is often influenced by temperature because it acts on the dissolution of salts in water [8].

Measuring electrical conductivity makes it possible to quickly but very roughly assess the overall mineralization of water and to follow its evolution. The electrical conductivity values obtained vary between 22 µS / cm and 969 µS / cm (Figure 2). Of the 83 sampling sessions, it should be noted that all the water points except Massenya drilling which is weakly mineralized.

The Massenya sample has a higher conductivity value than the other samples, but it is not higher than the WHO standard which is ≤ 2500 µS / cm.

In this study, the variations observed depend on the aquifer that contains these waters and the temperature of the borehole.
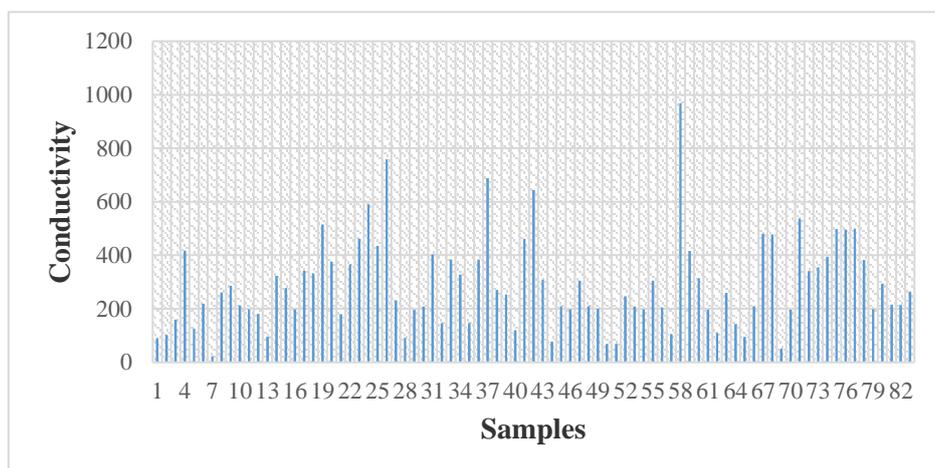
Figure 2. Conductivity variation.

- **Turbidity**

The turbidity is one of the important physical parameters for water quality, defining the presence of suspended solids in water and causes the muddy or turbid appearance of water body [9]. Very high values are found in the Massenya borehole (22.93 NTU). This recorded turbidity content exceeds the acceptable limit value for water intended for human consumption which is 5 NTU [10].

It should be noted that the least cloudy waters are those of the city of Ndjamena Koura, Klessoum, Aboussakine and Balabouda.

All values obtained comply with the Chadian national standard / WHO directives that stipulates that the turbidity must be ≤ 5 NTU. In the towns Massenya, Massenya Q la paix, Massenya Djouboulio and Tourli I, the aquifers of these waters consist of a clay or silty part. The turbidity of the water comes from the presence of suspended matter such as: clay, silt ... which gives a cloudy appearance to the water.

- **Total Dissolved Solids**

The level of dissolved solid or the level of dissolved salts varies significantly depending on the sampling point. The highest concentration of dissolved salts is observed in Ndjamena (379.0 mg/l).

The rate of dissolved salts varies according to the sampling points depending on the amount of dissolved matter in these waters.

- **Calcium (Ca^{2+})**

Calcium is an alkaline earth metal extremely widespread in nature and in particular in limestone rocks in the form of carbonates. It is the major component of water hardness. In our water samples, the calcium contents vary from 6 mg / L to 106.52 mg / L (Figure 3). None of these waters therefore has a concentration greater than the WHO standard which is ≤ 200 mg /L.

This high content can be explained by the nature of the aquifer, which is partly made up of limestone. According to J. L. Potelon et al [11], calcium is a metal extremely widespread in nature and in particular in limestone rocks in the form of carbonates ($CaCO_3$). It is encountered in almost all natural waters. The presence of Ca^{2+} in the samples analyzed is directly linked to the geological nature of the terrain crossed. The values obtained comply with the Chadian national water standard /WHO which stipulates that the maximum concentration of Ca^{2+} ≤ 200 mg /L.
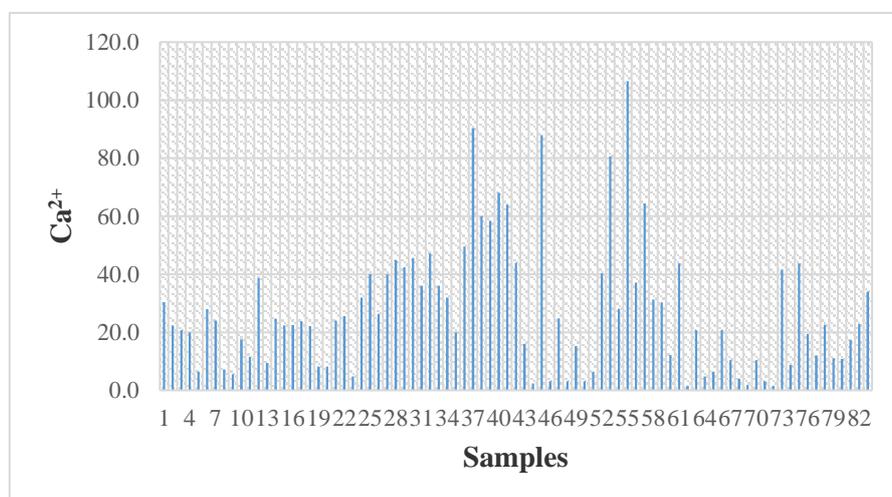
Figure 3. Ca^{2+} variation.

- **Sodium (Na^+)**

The sodium ion analysis of the water samples over all 83 sampling series gives us levels ranging from 1.7 to 89 mg / L (Figure 4), which is harmless to health, limit value recommended by the WHO being   ≤ 200 mg / L. Sodium is generally encountered in the form of sodium chloride salt.

The values obtained in this study comply with the Chadian National Standard/WHO Directive which stipulates that the content of sodium ions in drinking water must be ≤ 200 mg /L.
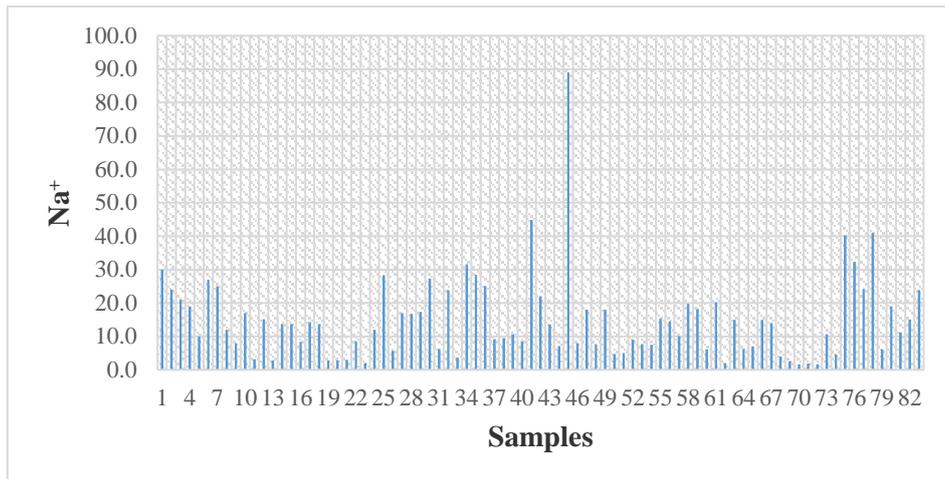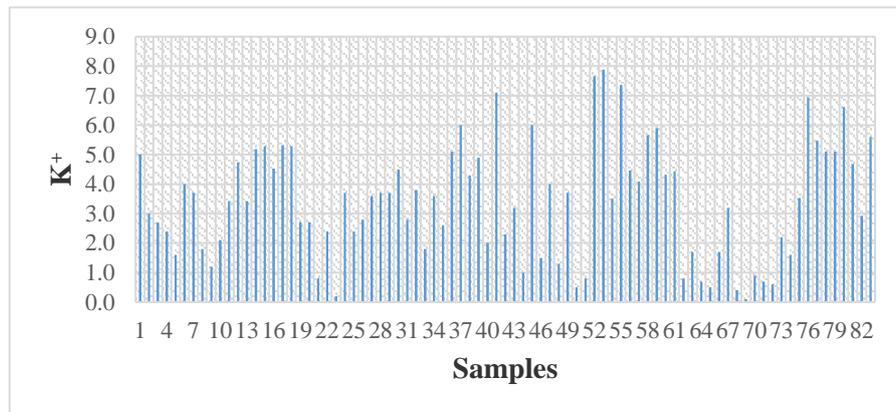
Figure 4. Na⁺ variation.

- **Potassium (K⁺)**

   The potassium values that we measured by flame atomic absorption spectrometry (Figure 5) range from 0.1 to 7.88 mg / L. They are good below WHO standard.
   The presence of these potassium concentrations is due to the rocks crossed. According to Potelon et al [11], potassium is a natural element in waters where it's almost constant concentration usually does not exceed 10 to 15 mg /L. Furthermore, the values obtained in this study comply with the Chadian National Standard /WHO Directive which stipulates that the content of sodium ions in in drinking water must be ≤ 12 mg.

Figure 5. K⁺ variation.

- **Chloride (Cl⁻)**

   Chlorides are important inorganic anions present in varying concentrations in natural waters and constitute an indicator of pollution. Their presence in groundwater may indicate anthropogenic contamination because of their existence in the urine as well as in the maintenance products.
   According to Figure 6, the contents vary between 0.65 and 67 mg / L. The maximum value, for its part, is encountered in the N'Djamena (Zozi) drilling.
   The values obtained in this work comply with the Chadian National Standard/WHO Directives which indicates that the chloride ion content in drinking water must be ≤ 250 mg /L.
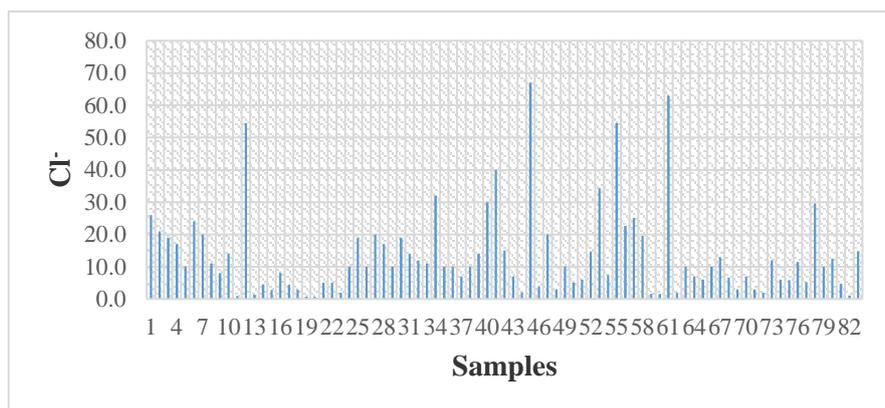
Figure 6. Cl⁻ variation.

- **Sulfate SO_4^{2-}**

Sulfate occurs naturally in water as a result of leaching from gypsum and other common minerals. Discharge of industrial wastes and domestic sewage tends to increase its concentration [12]. In this study area the values of this parameter in the waters studied are very variable as can be seen in the Figure 7. They oscillate between 0 and 58 mg / L, values below WHO standards (250 mg / L).

The presence of a high concentration of SO_4^{2-} is due to the rocks crossed by the water. In this area the geology consists of sedimentary rocks, gypsum ($CaSO_4$). According to Meybeck et al [13], the presence of sulfate in unpolluted waters invokes the presence of gypsum with a concentration varying between 0 to 58 mg /L. The waters analyzed comply with the National Standard / WHO Directive which provides for a concentration ≤ 250 mg /L.
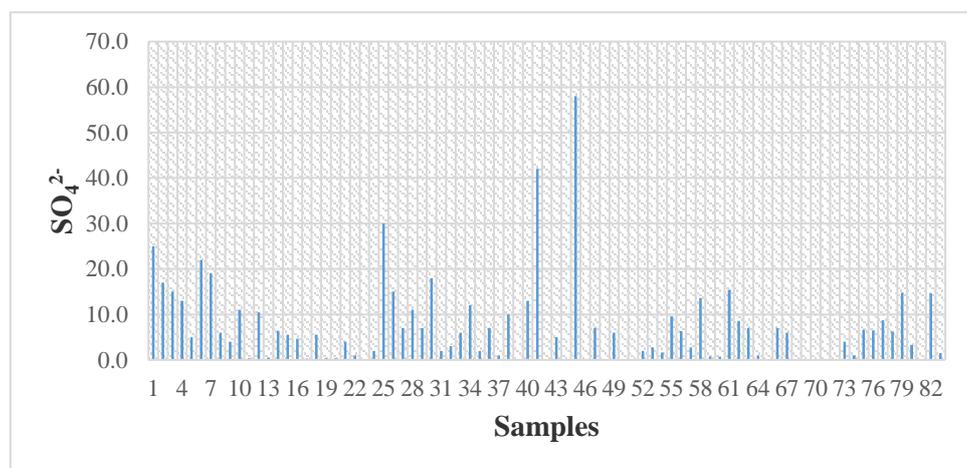
Figure 7. Sulfate SO_4^{2-} variation.

- **Bicarbonate (HCO_3^-)**

Using the measured Complete Alkalimetric Title (TAC) values, we determined the bicarbonate content in the water samples (Figure 8). There is no WHO standard for this element, but a high concentration of bicarbonates gives a salty flavor to the water. The levels vary from 7.3 to 433.24 mg / L.
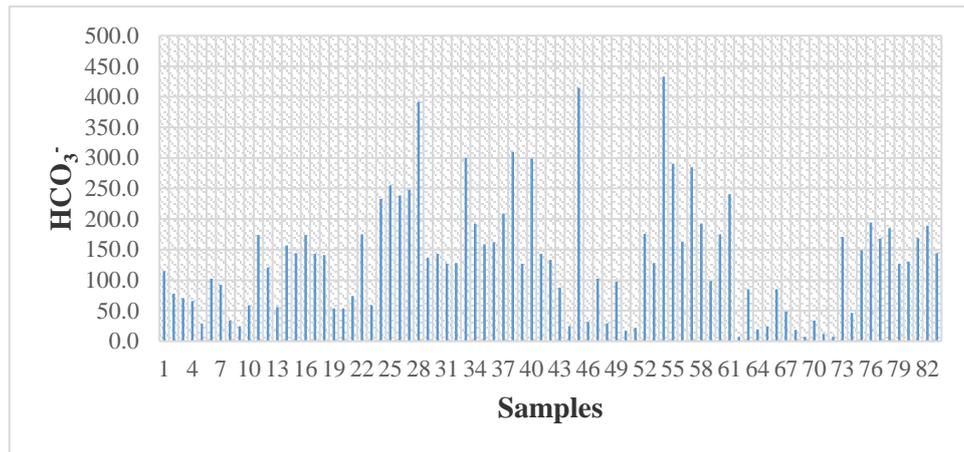
Figure 8. HCO_3^- variation.

- **Magnesium (Mg^{2+})**

Magnesium is the second most important element in water hardness after calcium. The concentration of magnesium varies according to the traversed terrain during the infiltration [14]. Water rich in magnesium is beneficial for the consumer and has important intakes especially in cardiac and vascular function; it acts on cardiac excitability and vascular tone, contractility, reactivity and growth [15].

He is present in the waters of this region at levels ranging from 0.47 to 35.5 mg / L (Figure 9). These levels are lower than the WHO accepted standard for magnesium, which is 50 mg / L.
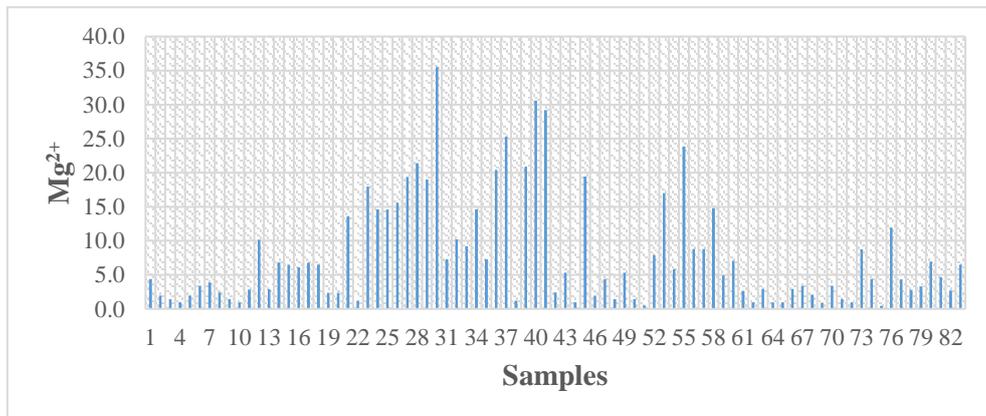
Figure 9. Mg^{2+} variation.

- **Nitrate (NO_3^-)**

In the region studied, the nitrate contents vary during the study period. It should be noted that in most of the samples analyzed, there is no presence of high nitrate ions.

According to the Chadian national standard/WHO directives, the concentration of NO_3^- must not exceed 50 mg/L. All the samples analyzed comply with the standard because the NO_3^- concentrations obtained remain low and below the limits of said standard.
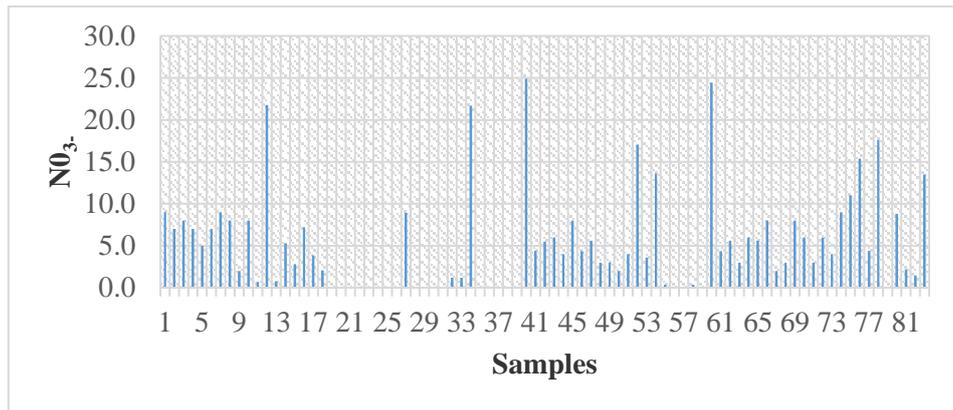
Figure 10. NO_3^- variation.

• **Ammonium (NH_4^+)**

It should be noted that in most of the samples analyzed the presence of ammonium is remarkable. According to the Chadian national standard / WHO directives, the NH_4^+ ammonium concentration must not exceed 1.5 mg / L. Some of the samples analyzed don't comply with the standard because the NH_4^+ ammonium concentrations obtained remain high and greater than the limits of said standard.
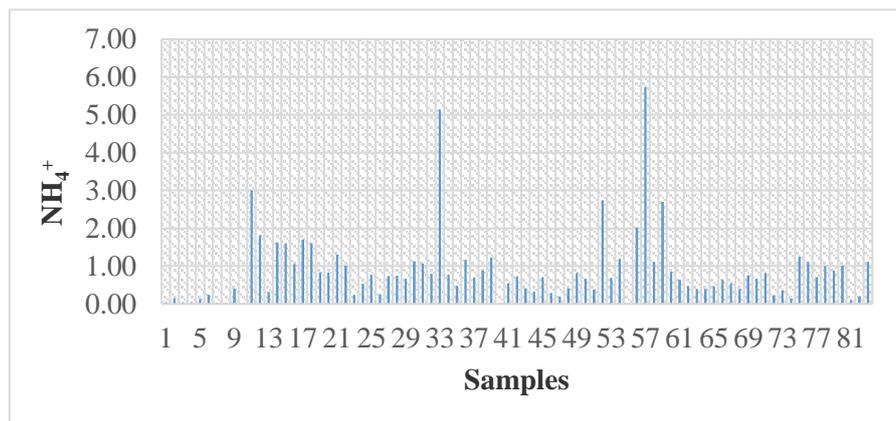

Figure 11. NH_4^+ variation.

• **Iron (Fe^{2+})**

Iron is a fairly abundant element in rocks in the form of silicates, oxides and hydroxides, carbonates and sulphides. Iron is soluble in the Fe ++ ion state (ferrous ion) but insoluble in the Fe +++ state (ferric ion). The value of the oxidation-reduction potential (Eh) of the medium therefore conditions its solubility and the iron content of the water. Captive aquifers isolated from exchanges with the surface are in reducing conditions: their water is ferruginous. This dissolved iron precipitates in an oxidizing medium, in particular at the sources and at the outlet of the pipes.

The presence of iron in the water can promote the proliferation of certain strains of bacteria which precipitate the iron where the pipes corrode. The water is ferruginous, in particular in certain layers of NDjamena and Ba-illi. A specific treatment is then necessary (precipitation in an oxidizing medium) [16]. The total iron contents in the study region vary from 0.00 mg / L to 1.4 mg / L (Figure 12), the iron concentration in the region is above the recommended standard.
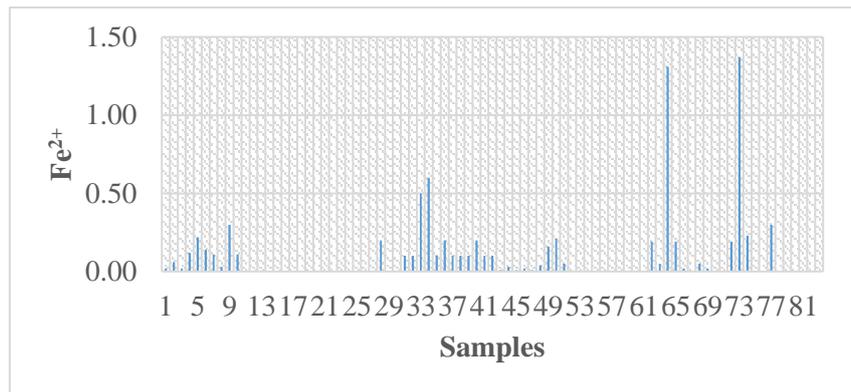
Figure 12. Fe^{2+} variation.

- **Hydro chemical facies**

The Piper diagram (Figure 13) shows the chemical facies set of water samples. It is composed of two triangles making it possible to modify the cationic facies and the anionic facies and of a rhombus synthesizing the global facies.

Our piper diagrams corresponding to the water samples from the eighty-three collection sessions are shown in Figure 13.

In Figures 13a, 13b and 13c we observe in the triangle of anions a predominance of bicarbonates, which reflects a facies bicarbonate. In the triangle of cations, there are no dominant ions, which translates a mixed facies of sodium, potassium, calcium and magnesian. These results are confirmed in the diamond where we have a global calcium and magnesian bicarbonate facies.
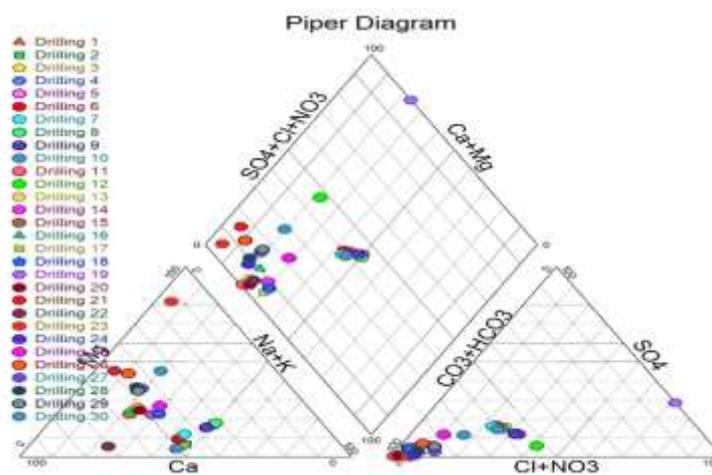

Figure 13a. Paper Diagram.

Paper diagram 13a of the samples analyzed show 86.66% of the calcium and magnesian bicarbonate facies and 3.33% of the calcium and magnesian chloride and sulfate facies.
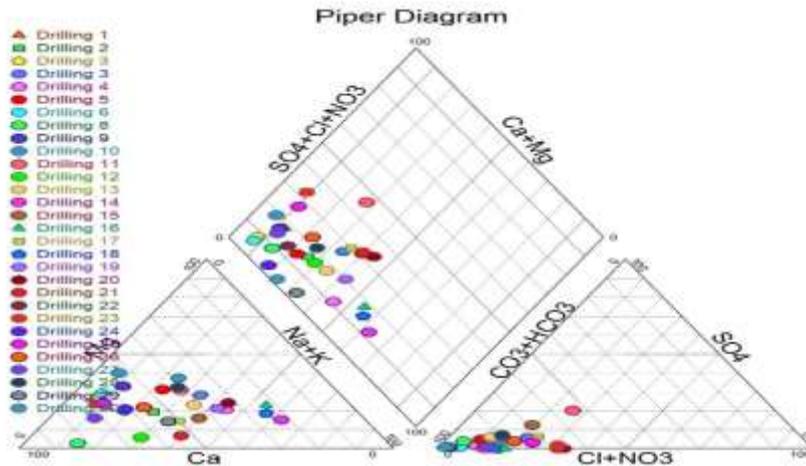
Figure 13b: Paper Diagram

Paper diagram 13b of the samples analyzed show 90% of calcium and magnesium bicarbonate facies and 10% of sodium and potassium bicarbonate.
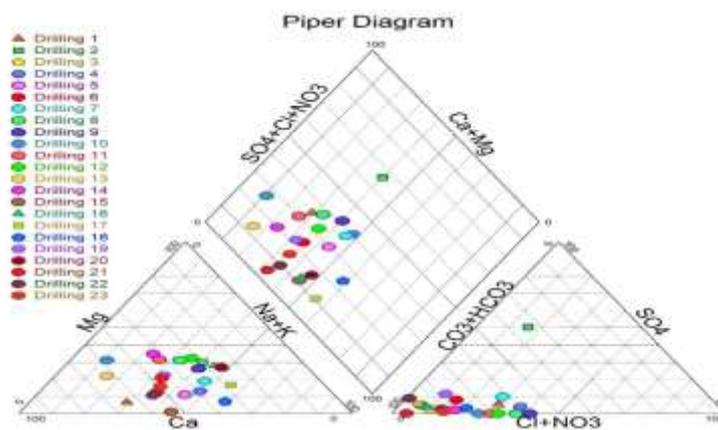

Figure 13c. Paper Diagram.

Paper diagram 13c of the samples analyzed show 82.60% of calcium and magnesian bicarbonate facies, 8.69% of sodium and potassium bicarbonate and 4.34% of calcium and magnesian chloride sulfate.

Principal Component Analysis

The method of principal component analysis (PCA) is widely used to interpret hydro chemical data. For the data processing in principal component analysis, 12 variables were used in this case pH, EC, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NH_4^+, NO_3^- , HCO_3^- and Fe^{2+}

The total variance gives us an idea of the degree of information that each component represents.

The first component alone represents 34.19% of all the variable information while it is these five variables that represent the total information.

If we regroup these five variables, we will have 74.18% of the information of all the variables so there is no point in working on the whole set of variables because its variables (or components) are reliable.

For more information, there are two methods of interpreting the total variance, either we choose variables which have a total greater than 1 and therefore in our case we have the components 1,2,3,4

and 5 and / or we choose variables of which by making their cumulative we can have 80% and in our case the software has chosen five variables which have a total greater than or equal to 1.

Table 2. Extraction Method, Principal Component Analysis.

	Total Variance Explained					
Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	4.103	34.195	34.195	4.103	34.195	34.195
2	1.640	13.663	47.858	1.640	13.663	47.858
3	1.132	9.434	57.292			
4	1.069	8.905	66.197			
5	.961	8.005	74.203			
6	.867	7.225	81.427			
7	.720	6.002	87.429			
8	.455	3.795	91.224			
9	.376	3.135	94.359			
10	.353	2.942	97.301			
11	.197	1.639	98.941			
12	.127	1.059	100.000			

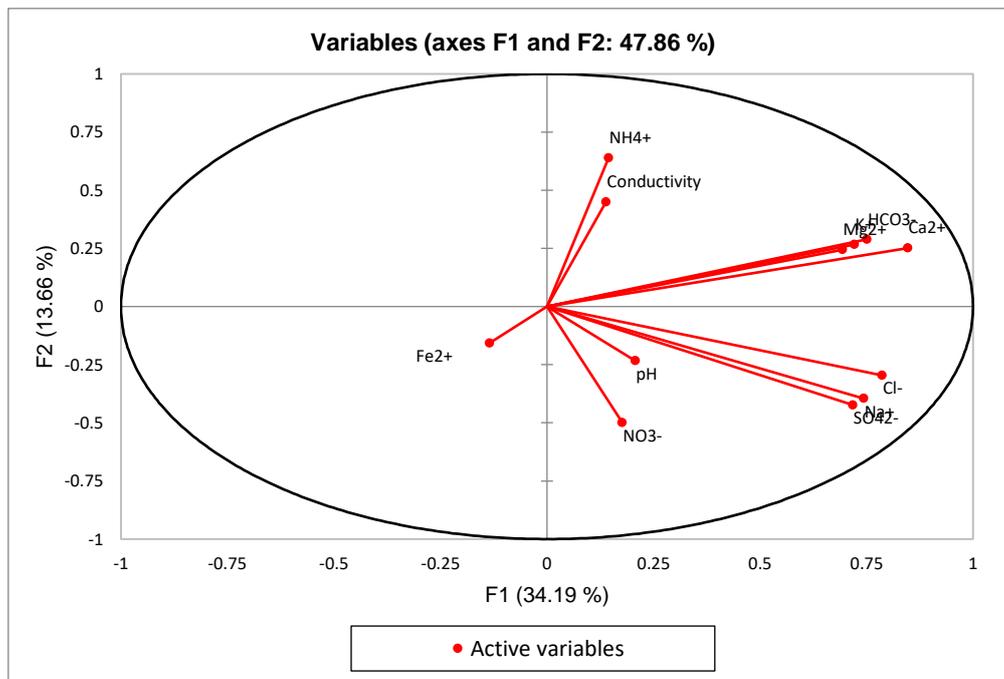**Representation of the Variables on the Factorial Plane F1 and F2**

Figure . correlation circle.

The correlation circle (Figure 15) shows that twelve variables taken into account in the PCA contribute to the definition of the factorial plane F1 x F2.

Analysis of the F1 and F2 factorial design shows that 47.86% variance is expressed. Factor 1 is expressed at 34.19% and represented mainly by: pH, EC, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NH_4^+, NO_3^-, but also by HCO_3^- ions. The F2 axis is expressed at 13.66% and represented by Iron.

Axis 1 is strongly correlated on the positive side with electrical conductivity, bicarbonates, ammonium, potassium, magnesium and calcium. This axis expresses both mineralization and organic pollution of the water. The conductivity measurement could therefore be sufficient to predict the quality of the water with regard to the above parameters.

This provides a simpler and faster way to monitor the water quality in an area. The results obtained are similar to those of Allhabo Ahmat [6] and Mahamat Seid et al. [7] who showed that some boreholes in Ndjamena have concentrations much higher than the WHO standard.

Conversely, axis 2 is strongly correlated on the negative side with pH and nitrate and on the positive side correlated with ammonium and electrical conductivity. This axis expresses less water mineralization compared to axis 1.

4. Discussion

The results corroborate with those of Allhabo Ahamat Alhabo, [6], Mahamat Seid Ali Malloum et al [7] reported in their research on the water quality of the city of NDjamena. These abnormal levels of iron and ammonium acquired in the drilling water are similar to those we obtained during this research. However, the high iron and ammonium contents recorded respectively in certain localities constitute a major problem for the populations. Ammonium is the most reduced form of nitrogen and is the end product of the degradation of organic and inorganic matter in soil and aquatic environments [17]. The presence of ammonium in percolating groundwater indicates anthropogenic contamination. In addition, this element also comes from the bacterial activity of the soil, agricultural and industrial waste [17]. In fact, iron gives water an unpleasant metallic taste and a reddish color which could be linked to the deoxygenation of the water by organic activity in the soil and in the unsaturated zone [18].

The results of physicochemical analyzes of groundwater from some manual boreholes in the Chari Baguirmi region show that the water is slightly acidic with pH varying between 4.81 and 6.3

In fact, in a humid tropical zone, this acidity would come from mainly from the decomposition of plant organic matter, with the production of CO_2 in the first layers of the soil [19-20-21]. The predominance of hydrogen carbonate ions (HCO_3^-) associated with the Ca^{2+} cation in the water sampled is thought to be a consequence of acid attack on the rocks, and is also a characteristic of groundwater in the basement regions of Chad. These two elements are at the origin of the calcium carbonate facies of water samples.

The waters studied are weakly mineralized but with fairly high mineralization at Massenya (969 $\mu S.cm^{-1}$). This low water mineralization according to Youan Ta et al. [22], could be explained by the very poorly soluble nature of the host rocks.

5. Conclusion

Water resources are threatened today by pollution which causes degradation of water quality. Surface pollutants can seep through the soil to the water table. The danger of pollution depends on the types and concentrations of the pollutants. The physicochemical quality of the groundwater from 83 manual boreholes in the region of the Chari Baguirmi region was evaluated while performing analyzes of 12 physicochemical parameters.

This study showed that some boreholes are not recommended for consumption as drinking water. The parameters which downgrade this groundwater as non-consumable drinking water are iron and ammonium.

Among the samples analyzed, the water samples retrieved from Dourbali, Ba-illi, Bousso and Massenya are of good quality and can be intended for human consumption. The other samples must be subjected to chemical treatments. To avoid the possibility of any health risk, it is recommended to treat water on a family scale by the use of hypochlorite, using a dropper, extend the drinking water network in rural areas, and design the sewerage network for wastewater disposal, garbage collection and protection of catchments.

Author contributions: ALLARAMADJI BEYAITAN BANTIN designed the conception and carried out the analysis of results. HONGPING WANG performed the experiments, XIA JUN edited the format and checked the language.

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Abbreviations

The following abbreviations are used in this manuscript

WHO: World Health Organization

PCA: Principal component analysis

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