IJESRT: 12(5), May, 2023 ISSN: 2277-9655

International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

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Website: www.ijesrt.com Mail: editor@ijesrt.com

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

HYDROCHEMICAL CHARACTERIZATION OF THE SUPERFICIAL AQUIFER OF DOBA, SOUTHERN CHAD

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ABSTRACT

Water is a very important resource and ensures the survival of man on a global scale. In the south of Chad, more precisely in (Doba), this resource is buried in vast areas made up of sedimentary formations (sands, sandstones). The latter host Cretaceous and Continental Terminal aquifers whose knowledge of chemical and piezometric properties is limited. The objective of this work aims to know the water level, characterize the nature of groundwater from the chemical elements and by determining the relationships between the ions and the origin of the mineralization of the groundwater. A total of 31 in situ measurements (temperature, Ph, TDS, salinity, conductivity), 38 piezometric measurements and 25 water samples are taken during field campaigns during low water periods. After investigations, it appears that the piezometric heights vary from 359 to 423.88 m. The highest point is in the South-West at Békondjo 2 (P13) and the depressions in the center at Ndounambo (F4), a little to the East at Dogouti 1 (F1) and at Bedogo in the North-West (P20). Temperatures range from 21.2 (well P5 at Bo bouete) to 33.3°C (well F1 at Dogouti). All the water sampled has pH values between 7.11 (Békondjo F6 borehole) and 8.89 (Ndounambo P8 well), thus indicating a basic character. The waters have conductivities between 17.9 (well P15 at Mismadji) and 368 µs.cm-1 (well P21 at Divers). TDS values range from 13.1 to 261 mg/l. The distribution of the waters analyzed in the piper diagram shows two categories of water (groundwater, surface) divided into three facies: Sodic and potassium carbonate Na-K-(CO3), calcium bicarbonate and magnesium Ca-Mg-(HCO3 + CO3) facies as well as the sodium and potassium chloride facies. The waters have an average nitrate concentration (between 3 and 19 mg/l). Geochemical modeling shows that the waters are mostly supersaturated with respect to dolomite, balanced majority and undersaturated with respect to aragonite and calcite. The carbonated and bicarbonated waters composed mainly of calcite, dolomite, show that the origin of the mineralization of the waters of two layers would be linked to the lithological nature and by the dissolution of the minerals. Geochemical modeling shows that the waters are mostly supersaturated with respect to dolomite, balanced majority and undersaturated with respect to aragonite and calcite. The carbonated and bicarbonated waters composed mainly of calcite, dolomite, show that the origin of the mineralization of the waters of two layers would be linked to the lithological nature and by the dissolution of the minerals. Geochemical modeling shows that the waters are mostly supersaturated with respect to dolomite, balanced majority and undersaturated with respect to aragonite and calcite. The carbonated and bicarbonated waters composed mainly of calcite, dolomite, show that the origin of the mineralization of the waters of two layers would be linked to the lithological nature and by the dissolution of the minerals.

Keywords: Hydrochemistry, Aquifer, groundwater, Mineralization, Doba

1. INTRODUCTION

In the world in general, the problem of water is at the heart of the challenges of sustainable development. Water resources have characteristics that distinguish them from other resources because they are permanent, renewable, essential to life and make up 65% of the human body (Laurent, 2012). From an exploitation point of view, groundwater is the most used or exploited for consumption

(Margat J., 2019). Many books deal with issues related to surface and groundwater resources in the Lake Chad Basin (Schneider et al., 1992; Mahamat Nour et al (2021); Mahamat Nour et al (2017); Gaultier, 2004; Abderamane, 2012), as well as land and water degradation trends in ecosystems (LCBC, 2008, GEF et al., 2012; Herrmann et al., 1993. Hence the importance of water resources in sedimentary basins in Chad. In Chad, 56% of households consume water from an improved source, in 36% of cases the water consumed by households comes from unprotected dug wells or an unprotected water source (INSEED , 2015). Although surface water (river, river, backwater, stream, lake, pond, etc.) is unfit for consumption, it is consumed by 8% of Chadian households (INSEED, 2015). In the study area where the number of the population is estimated at 796,453 (RGPH, 2009) i.e. a density of 33 inhabitants/Km2, the wells are very superficial so that during the rainy seasons, some open wells are submerged. by the waters. The quality of these waters deteriorates under the effect of pollution, which is either of urban origin, industrial and agricultural (Mansour, 2012; Ambouda J, 2016). The problem of water resources rests much more on the quality although it is available. Contrary to urban areas where water is supplied by an adequate transfer and treatment system, in the province of Doba, most of the water catchment works are wells, boreholes and surface water which are exploited directly. for consumption without treatment (Maoundobaye et al. 2015). Since these aquifers are superficial, there is a rapid infiltration through the ground, of waste or garbage which are sources of various pollutions. The study of the chemical behavior of water is also linked to the nature of the soil, the different environments crossed during infiltration, superficial inflows and the time the water stays (Thiry and Bariteau, 2003). In view of the problems related to the quality of groundwater, this study aims to deepen the hydrochemical study, in order to provide information on the exchanges of ions which govern these waters, knowledge of their potability and indicate the origin of their mineralization depending on the direction of groundwater flow.

2. GEOGRAPHICAL AND CLIMATIC CONTEXT

2.1 Study framework

The study area with an area of 269 km^2 is between 16°47'16.891"E and 17°6'18.826"E East longitude; and 8°34'12.959"N and 8°43'54.922"N north latitude (Figure 1). It is part of the province of Logone Oriental. The area encompasses several outlying neighborhoods and villages. The topography is flat, less rugged, and presents a relief varying from 373 to 403 m.

2.2 Climate framework

The study area belongs to the Sudanian climate (Aubreville, 1950) with two (2) seasons: a rainy season and a dry season.

- The rainy season includes a long season from April to October (figure 2), but most of the precipitation is concentrated between July and August.
- The dry season which begins from November to April.

These climatic conditions are influenced by the movement of air masses (FIT)which can change significantly from year to year. The fitmoves from south to north from January to August and return to the south from September to December (Suraud P., 1954).

3. GEOLOGICAL AND HYDROGEOLOGICAL CONTEXT

The study area is crossed from south to north by the Pendé River. In addition to this main watercourse, there are also some temporary watercourses. These observed watercourses have a dendritic drainage network characteristic of a low slope zone (Gregory et al., 1973). According to Schneider et al. (1992), two types of hydrogeological formations are identified: Cretaceous formations (Sandstones of Nubia) composed of conglomeratic sandstones, fine sandstones, argillites and Tertiary formations (Continental Terminal of the oligo-Miocene) made up of ferruginous sandstone, sands, clays, laterites. Depending on the depths, the geologist Mermillod (1960) gives the following indices in the vicinity of Doba:

- The Continental Terminal: from 0 to 700 m;
- The Cretaceous Marls: from 700 to 1500 m;
- The Continental Intercalaire: from 1500 to 3500 m.

In the Continental Terminal, the logs showed the homogeneity of the sand horizons, which suggests high permeability (Gac Jean-Yves, 1980), with flow rates varying between 17 m^3/h and 180 m^3/h. The aquifer is usually recharged by rainfall, drains to permanent streams. The groundwater level is shallow in the valleys (less than 10 m/ground); however, it can exceed 80 m in the plateau sector (Koros region). The deep aquifers are that of the Cretaceous. In the discontinuous basement aquifer, the maximum depth of drilling is 100 meters with specific flow rates of around 1 $m^3/h/m$, while in the alluvial zone it is 25 meters with flow rates between 1 and 8 m^3/h

4. MATERIALS AND METHODS

4.1 Hardware

Composed of water from wells, boreholes and surface waters, the material covered by this study is carried out on 25 water samples: nine (9) from boreholes, fourteen (14) from open wells and two (2) from of surface. All the waters were taken from the Cretaceous and Continental formations. This work was carried out in the low water period (March-April 2021).

4.2 Methodology for the hydrodynamic study

The piezometry study was based solely on the different static water levels in wells and boreholes. The various piezometric elevations enabled us to establish the piezometric maps using the Arcgis 10.8 software.

Methodology for the study of the physical parameters of water.

In the field, we measured the physical parameters (temperature, electrical conductivity, pH, salinity, total dissolved solids TDS) of the water using a two-electrode multi-parameter device.

4.4 Methodology for the study of chemical parameters of water

The analyzes were carried out at the National Water Laboratory. An analysis of the major elements (Ca^{2+}, Mg^{2+}, Na^+, K+, Cl-, SO_4^{2-} and HCO_3^-) and two trace elements (Fe, Mn) was carried out. We used devices and chemical reagents for water analysis. For the chemical parameters we used the flame spectrometry method (DR2800 spectrophotometer). Some elements are determined by the colorimetric method by assaying reagents such as bicarbonate, chloride.

For the interpretation of the results, we used software namely: R studio software, Arcgis 10.8, Phreeqs, Aquachem 2014.2 and Excel.

5. RESULTS AND DISCUSSION

5.1 Physical Parameters

The physical parameters characterize the quality of water and are numerous, but for this study, four parameters are determined (Temperature, pH, Electrical Conductivity, Total Dissolved Solids TDS). Groundwater temperatures vary between 21.2 and 33.3°C across all samples. Surface waters have temperatures close to 30°C. Temperatures increase slightly from South to North-East (P13 – F1, Figure 2) and from South to North-West (P13 – P20). This increase in low areas would be due to the influence of geothermal gradient at depth (Mahamat Nour et al., 2017). The high temperature of surface water and groundwater could create favorable conditions for pollution. The hydrogen potential is an important parameter for the interpretation of the results. It makes it possible to determine the degrees of aggressiveness of the water. All the water sampled has a pH ranging from 7.11 to 8.89 with an average of 8.13 (Table 1). These are basic waters. There is a slight increase in the pH of the dome (P13) towards the depression (P20), on the other hand on the axis P13 –F1, we observe a constant distribution and a homogeneity of the pH. The distribution of pHs according to their frequency in the histogram (figure 3) shows that 66.7% of the waters have pHs between 8 and 8.89 and 33.3% oscillate between 7.11 and 8. These pHs high in the dry season (March-April) are mainly due to the nature of the sedimentary rocks rich in basic minerals (Calcium, Sodium, potassium, calcium) and to the contact time of the waters with these minerals. The waters have conductivities between 17.9 and 368 µs.cm^{-1}.

The mineralization is low to average (less than 368 µs.cm^{-1}) and all the values are all overall below the standards set by the WHO, 2000 (ie 2500mg/l for drinking water). The Total Dissolved Solids (TDS) represent the total mineralization dissolved in the water which is none other than the sum of the concentrations of the dissolved elements. The TDS values are from 13.1 to 261 mg/l.

5.2 Chemical parameters

The low value of magnesium is 0.10 mg/l (observed in well P2 at Dogouti 2), on the other hand the high content is 2.43 and observed in well P18 at Madjo Doba. Calcium levels range from1.20 (in well P2 at Dogouti 2) to 5.12 (well P7 observed at Bessama 2), with an overall average of 2.77 mg/l.The sodium ion values vary between 2.60 mg/l (Well P2 at Dogouti 2) and 11 mg/l (Well P18 observed at Madjo Doba) over the entire aquifer, with an average of 5. 24mg/l. The distribution of potassium levels is relatively low with an average of 0.47 mg/l in all groundwater. The minimum and maximum values are respectively 0.10 mg/l (well P16 and P17 respectively at Maihondo and Mismadji) and 1.10 mg/l (well P7 at Béssama 2). The most abundant anion in Doba groundwater is bicarbonate (HCO3-). The abundance of the anions is presented in the following order: HCO3- > NO3- > Cl- > F- Table 2). The bicarbonate contents of groundwater vary from4.39 mg/l (in boreholes F5 and F17 respectively at Keureu and Mismadji) to 26.84 mg/l (in borehole F18 at Madjo Doba). Chloride contents vary from 1 mg/l (in borehole F17 at Mismadji) to 6 mg/l (borehole F7 at Béssama 2). The waters have average nitrate levels. It ranges from 3 mg/l (in borehole F21 at Ferrick yacoub) to 19 mg/l (in borehole F18 at Madjo Doba) with a general average of 9.03 mg/l. The waters are characterized by sodium and potassium bicarbonate, calcium and magnesium bicarbonate, sodium chloride and potassium facies (Figure 2).

The piezometric map (Figure 3) shows that water circulation takes place from South to North; from South to North-West and from South to North-East (Schneider et al., (1992; Amboudja et al., 2016). The slope is relatively low and varies from 0.41 to 1.7%. In general, although the slopes are low, they play a very important role in mineralization and the transport of minerals to the depressions (Abderamane, 2012).

5.3 Principal component analysis

The projection of the variables along the factorial axes F1 – F2 shows that F1 alone represents 44% (Figure 4) of the total percentage of the cloud of points representative of the samples. The axis directing the vertical F2 factor gives 16.5% of the variance. We can therefore consider the F1 axis as being the axis of mineralization because it is the pole of concentration of anions and cations. Around this axis, we find highly mineralized species (Ca^{2+}, Mg^{2+}, K^+, Na^+, HCO_3^-, NO_3^-, Cl^-) with a very high contribution rate. This projection of the variables shows that along the F1 axis, the mineralization increases from South to West, from South to North-East (Figure 4).

5.4 Groundwater Mineralization Process and Basic Exchange Index

The Ca^{2+}/Mg^{2+} (Figure 5) and Cl^- /Na^+ (Figure 5) diagrams show the dissolution of calcium and sodium in water. The Cl- vs Na+ diagram shows that almost all of the points are located above the equilibrium line. There is therefore a net loss in chloride compared to sodium. This could be explained by the water/rock interaction and the weathering process. Excess calcium would appear in the Ca^{2+} vs Cl^- diagram (Figure 5). The diagram of Ca^{2+} vs HCO_3^- shows a dissolution of carbonates

(Figure 5). The content of calcium ions in the waters could be explained by a longer residence time within the aquifer and the enrichment in sodium could be explained by the passage of the waters in contact with the top of the aquifer or dissolving sodium-rich minerals. The setting up of the bicarbonates comes from the carbonated sediments (calcite, aragonites). It is also linked to the contributions of CO2 from meteoric waters and the soil. A nitrate content above 10 mg/l indicates an anthropogenic contribution (Blum et al. 2002).

The exchange index (ieb) expresses the cationic exchanges within an aquifer (Schöeller, 1962). The base exchange index is calculated by the formula: ([Cl] – [Na + K]) / [Cl]. If ieb < 0, the calcium in the water is exchanged for sodium or potassium within the formation; if ieb> 0 then there is fixation of sodium or potassium and solubilization of calcium. In our case, the basic exchange index is negative for all the waters sampled (Table 3). In this case, there is substitution of the calcium of the water against the sodium of the clays (or potassium) from where the high content of Sodium in the waters.

5.5 Water saturation indices

A geochemical simulation was made on the physical parameters (temperature, conductivity and ph). The software used for the geochemical modeling is the PHREEQC V.2.16 software (Parkhurst et al., 1999). It is used to calculate the saturation index (SI) by the formula:
IS = Log PAI/K (Debye and Hückel, 1923).
PAI: Product of activity of the ions concerned;
K: the solubility product of the mineral considered.
If: IS > 0.2: the water is supersaturated with respect to a mineral. The mineral would also tend to precipitate (Subyani, 2005; Cidu et al., 2009);
if -0.2 < IS < 0.2: the sample is in equilibrium;
When IS <-0.2: the water is aggressive, undersaturated with respect to a mineral. The mineral tends to dissolve.
Table 4 shows the results of the modeling (Types of minerals identified in groundwater according to the saturation index.

6. CONCLUSION

This study allowed us to highlight the direction of groundwater circulation oriented from south to north-west, from south to north and from south to north-east. The direction of circulation of these waters plays a very important role in the leaching and alteration of minerals, thus increasing the rate of mineralization of the waters in the catchment works located in the depression zones. The study of the contents of major elements shows that the mineralization of the waters is average and is controlled much more by sodium, bicarbonate, nitrate, chloride, and calcium. The waters have a basic pH with average concentrations of nitrates and acceptable compared to WHO standards. The factors that seem to control the physico-chemical quality of groundwater in the study area are the lithological nature of the soils, the urban and environmental environment represented by anthropogenic actions. The present study was of paramount importance to us on the study of the mineralization of groundwater but nevertheless remains to be completed with regard to the origin of the water and the mechanism of recharge.

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Tables and Figures

Table 1: Statistics of physical parameters of groundwater

Total statistical parameters (N = 31)				
	Minimum	Maximum	Mean	Standard Deviation
pH	7.11	8.89	8.13	0.54
EC	17.9	368	94.03	84.54
temperature	21.2	33.3	28.56	2.24
Salt	16.6	223	65.38	52.65
TDS	13.1	261	72.03	61.92

Table 2: Statistics of chemical parameters of groundwater

Total statistical parameters (N = 25)				
	Minimum	Maximum	Mean	Standard deviation
Turbo (NTU)	0	31	7.03	9.56
DT (CaCO3)	3.6	22	10.25	4.83
Ca2+	1.2	5.12	2.77	1.18
Mg2+	0.1	2.43	0.81	0.54
K+	0.1	1.1	0.47	0.26
Na+	2.6	11	5.24	2.26
HCO3-	4.39	26.84	12.41	5.92

Cl-	1	6	2.75	1.29
SO42-	0	0	0	0
NO3-	3	19	9.03	4.5
F-	0	1	0.06	0.2
Fe	0.01	0.3	0.06	0.08
min	0	0.07	0.01	0.02
NH4+	0	5.66	1.54	1.67

Table 3: Basic Groundwater Exchange Indices

Works	Na+K	Cl-	ieb
P1	5.4	2	-1.7
P2	2.8	1.3	-1.13
P3	5.8	2.6	-1.23
P4	3.42	1.8	-0.9
F5	2.89	1.9	-0.52
F6	5.43	2.5	-1.17
P7	11.1	6	-0.85
F8	5.1	1.9	-1.68
F9	4.48	2.1	-1.133
P10	4.3	2	-1.15
F11	8.7	4.1	-1.12
P12	4.4	2	-1.2
P13	5.8	2.3	-1.52
F14	7.6	2.7	-1.81
P15	9.8	4.3	-1.27
P16	3.1	1.1	-1.81
P17	2.9	1	-1.9
P18	12	5	-1.4
S19	6.4	2.2	-1.901
F20	6.6	1.6	-3.15
F21	3.4	3.1	-0.09
P22	4.8	3.7	-0.29
S23	6.6	4.5	-0.46
P24	4.6	3.1	-0.48
F25	5.4	3.9	-0.38

Table 4: Groundwater saturation indices

Works	SI.CaCO3 Aragonite	SI.CaCO3 calcite	SI.CaMg(CO3)2 Dolomite	MnOOH Manganite	FeCO3 Siderite	Fe2O3 Hematite	H2 H2(g)	NaCl halite

P1	0.17	0.31	0.95	-0.1	-0.28	22.23	-24.28	-6.77
P2	-0.05	0.09	0.54	1.44	-2.85	21.89	-25.6	-7.68
P3	2.21	2.35	4.79	-0.72	3.85	22.84	-24.5	-3.98
P4	-0.35	-0.2	-0.13	0	-0.67	26.57	-23.08	-7.39
F5	-0.06	0.08	0.49	-2.66	1.99	23.23	-22.32	-5.95
F6	-0.37	-0.23	-0.1	-2.32	1.04	22.97	-22.72	-6.65
P7	0.41	0.55	1.42	-0.07	0.08	23.57	-24.22	-6.44
F8	-0.23	-0.09	0.16	-2.05	1.12	23.19	-22.88	-6.55
F9	0.63	0.77	1.88	1.57	-1.81	22.94	-25.46	-6.73
P10	0.04	0.18	0.7	-0.51	-0.02	23.19	-24	-6.79
F11	-0.23	-0.09	0.15	-1.81	1.04	23.25	-23.06	-6.61
P12	-0.35	-0.21	-0.1	-0.58	-0.33	22.83	-24.06	-7.24
P13	-0.53	-0.39	-0.44	-1.52	0.39	22.87	-23.38	-7.1
F14	-0.93	-0.79	-1.23	-3.17	1.13	22.18	-22.22	-6.93
P15	-0.43	-0.29	-0.23	-2.4	1.3	23.01	-22.66	-6.6
P16	-0.28	-0.14	0.1	0.45	-1.9	22.16	-24.88	-7.62
P17	0.14	0.28	0.92	0.81	-1.62	22.62	-25.02	-7.17
P18	0.58	0.72	1.77	0.36	-0.35	23.5	-24.52	-6.4
S19	0.17	0.31	0.98	0.87	-1.66	22.62	-25.6	-7.16
F20	0.2	0.34	1.05	0.6	-1.43	22.69	-24.84	-7.05
F21	2.43	2.56	5.22	2.18	0.38	25.57	-25.36	-4.74
P22	1.22	1.36	3.04	1.13	-0.33	24.08	-24.92	-5.7
S23	0.23	0.37	1.11	1.12	-1.94	22.53	-25.24	-7.17
P24	1.35	1.49	3.27	1.31	-0.31	24.23	-25.02	-5.6
F25	0.15	0.29	0.95	0.75	-1.71	22.53	-24.98	-7.18

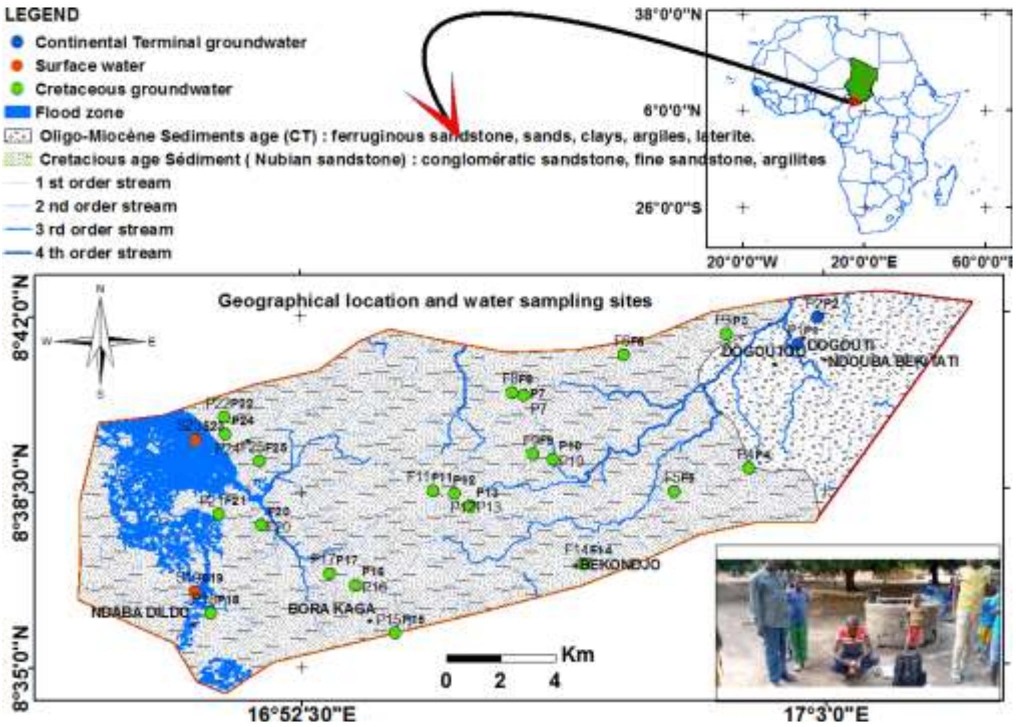

Figure 1: geographical location and water sampling sites

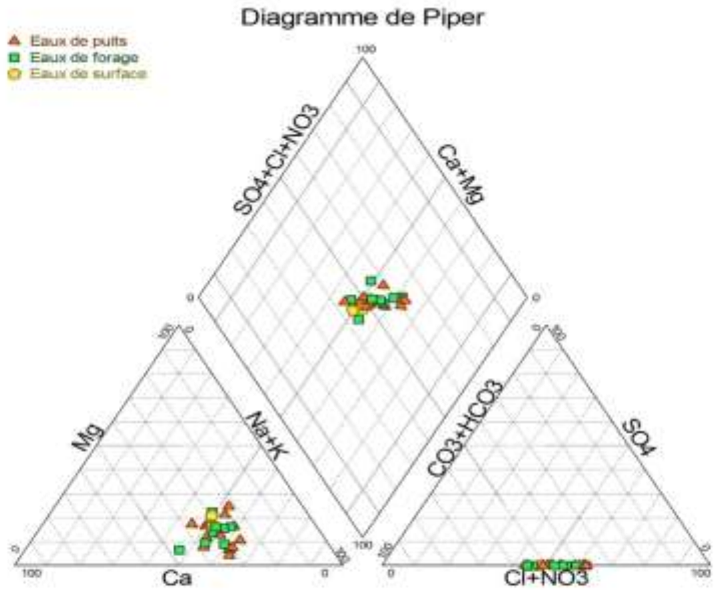

Figure 2: Chemical facies of the analyzed waters

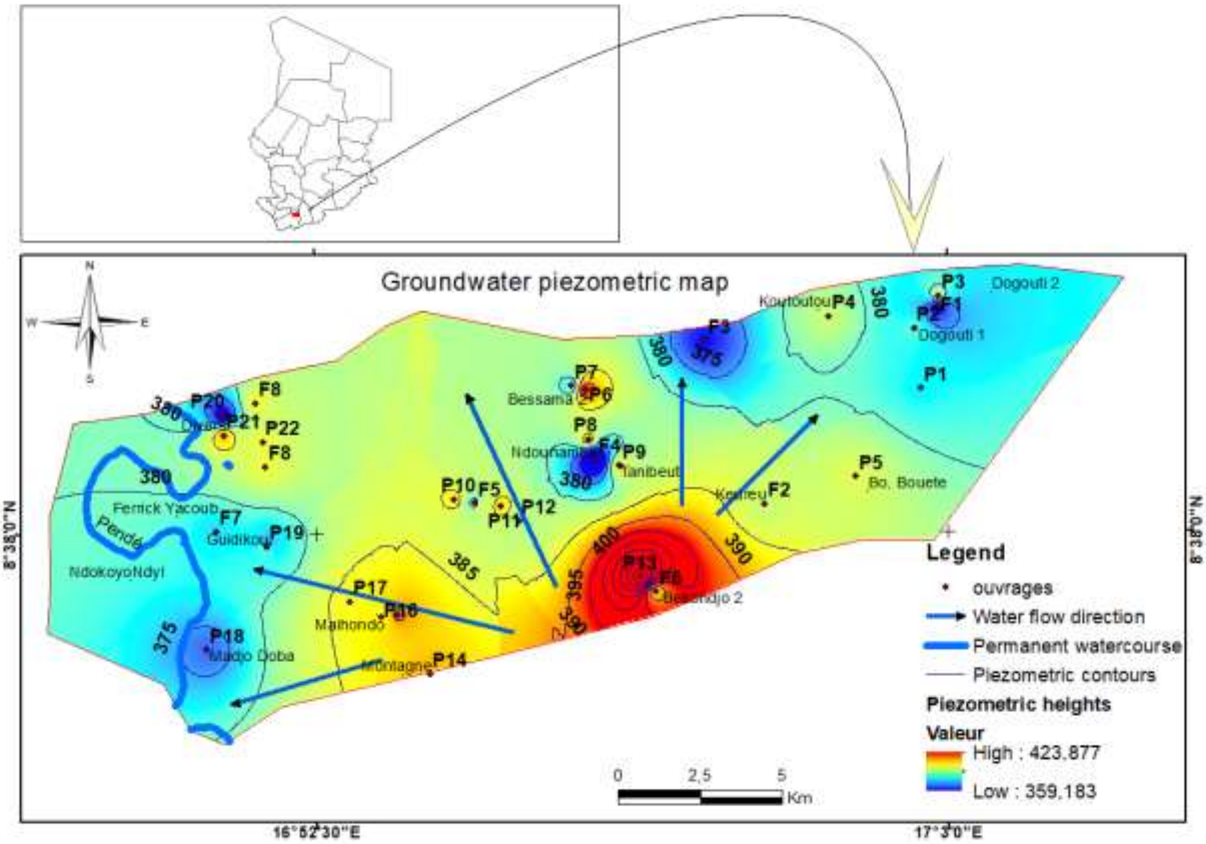

Figure 3: Piezometric map during low water period

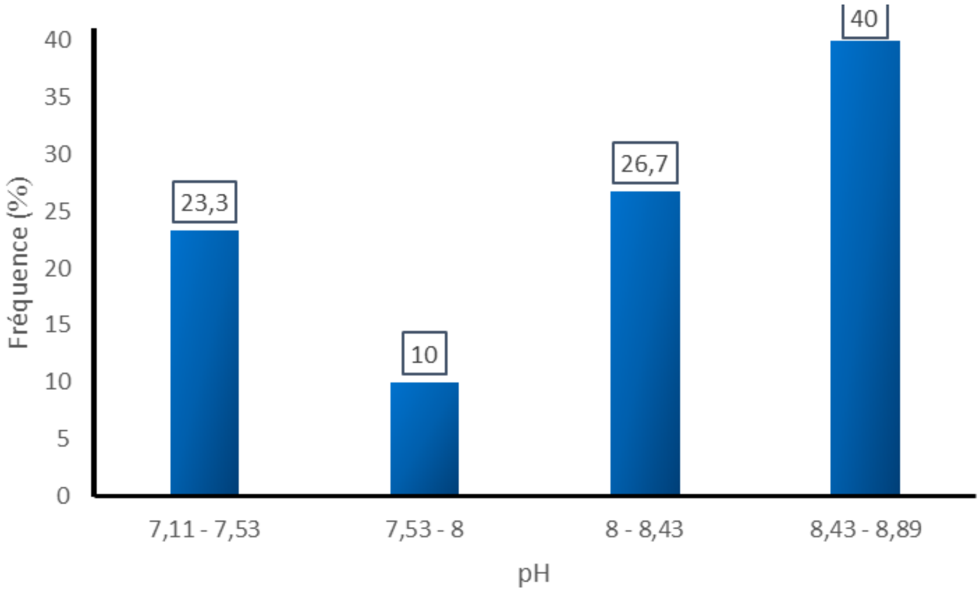

Figure 4: pH frequency histogram

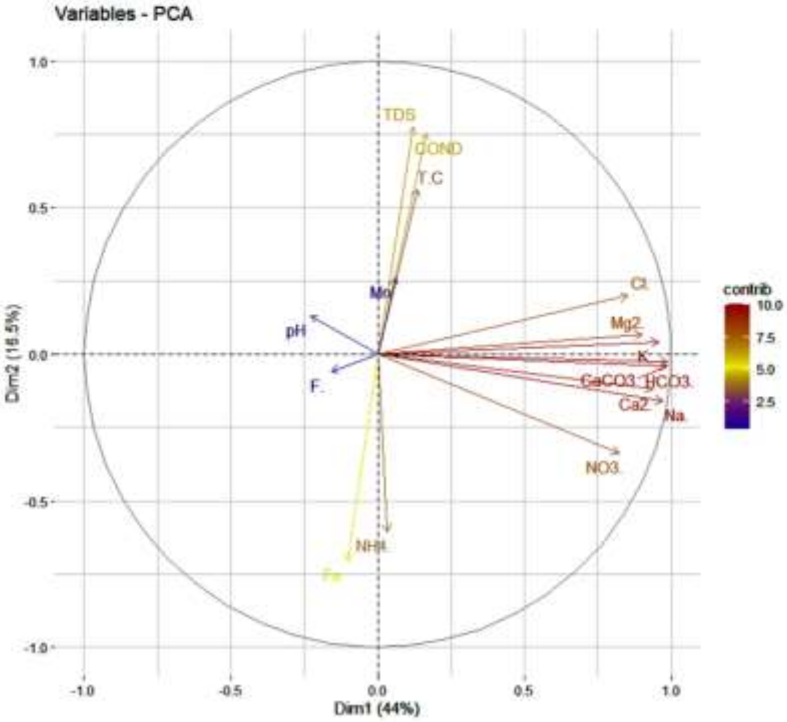

Figure 5: variable projection

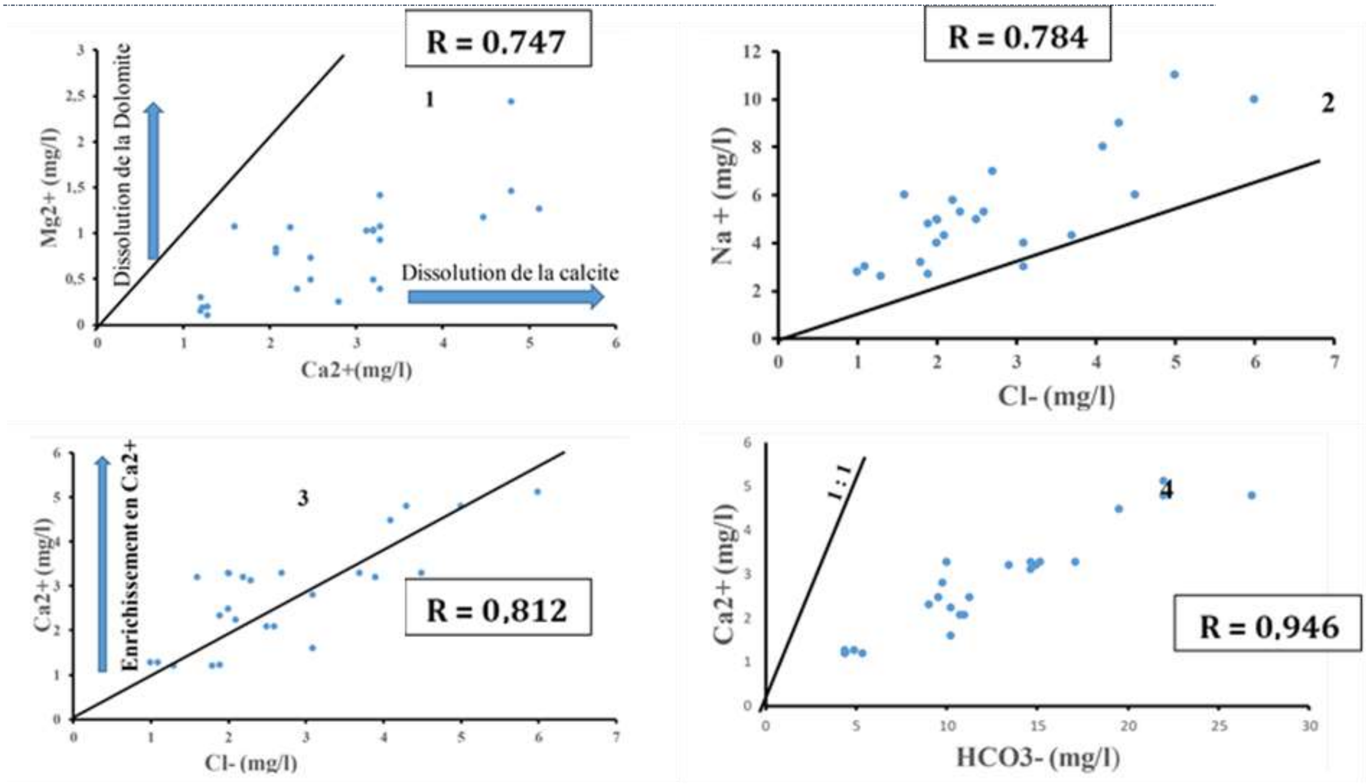

Figure 6: Ca2+ vs. Mg2+ diagram (1); Cl- vs. Na+ (2); Cl- vs. Ca2+ (3);Ca2+ vs. HCO3-(4)