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Hydrogeochemistry of boreholes's waters from Continental Terminal, basement rock and Korama geological formations (Zinder, Niger)

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Abstract

In arid and semi-arid areas, surface water resources are scarce or totally unavailable during the year. Consequently, groundwater resources remain the principal source of drinking water. In addition to this, there are some variations in water mineralization across different areas within the same aquifer. The present study aimed to understand the hydrogeochemistry of waters from borehole through the continental terminal, basement rock, and Korama formations in the Zinder region. To reach this objective, thirteen (13) boreholes were chosen and fifty two (52) samples were collected and analyzed over a year. The Water Quality Index (WQI) was calculated to determine the water types and their potential uses. The hydrochemical characteristics of the water were established based on the Schöeller-Berkaloff model. The Water Quality Index (WQI) showed generally good water quality. However, 23.1% of the water sources are unsuitable for drinking due to nitrate ion concentration exceeding WHO's standards. The water showed two major facies: a bicarbonate facies in 84.6% of the boreholes with calcium and sodium potassium poles and a chloride facies observed in 15.4% of the boreholes with a calcium pole. The mineralization of this water could be attributed to the surrounding rock, the transfer of water originating either from the Korama aquifer (due to its high permeability and low water level) or from the bedrock (due to its fault), and anthropogenic inputs. In order to globally understand the hydrogeochemistry of these waters, there is an need to support this study by the monitoring of certain isotopic signatures to better discriminate the water transfer as well as the mineralization.

Keywords: Hydrogeochemistry, WQI, Schöeller-Berkaloff diagram, Water pollution, Zinder.

Introduction

In recent years, climate change has significantly impacted Sahelian populations, resulting in a considerable decrease in rainfall[1,2] and the degradation of surface conditions[3]. Groundwater resources remain generally the principal water source for the populations of the Zinder region particularly during the long dry season and most often all the year[4].

Although this resource is essential for life and socio-economic development, the groundwater in the Korama, continental terminal, and basement rock formations is currently declining in both quality and quantity due to climatic and human influences. Indeed, high concentrations of nitrates and sulphates have been observed in some wells capturing these resources[5,6].

It is therefore essential to gain a better understanding of these resources[7] through monitoring their quality. This study was conducted in this context and aimed to determine the water quality status and the origin of the different facies of waters in this area.

Material and methods

Study area: The Zinder region is located in the east-central part of the country between 13°48' and 17°30' North latitude, and 7° 20' and 12°00' East longitude[4]. The landscape of the region is generally composed of mid-altitude plateaus, low plateaus, and low-lying plains[8].

In eastern Niger, the two mountain areas are the Zinder and Gouré massifs. They are located between the Lake Chad basin to the east and the Niger River basin (Iullemeden) to the west[4]. These two mountain area rise from an eruptive or metamorphic peneplain covered with regs and granite boulders in the north, or from a sandy cover in the south, where the low relief forms the Korama basin[9]. In this area, annual rainfall varies from 100 to 300 mm[10].

According to Faure[11], the geology of the Damagaram Mounio area is characterized by oldest rocks including marls, dolomites, and impure limestones with sandstone zones and a thick conglomeratic base. This calcic series is followed by a thick siliceous series ending in a limestone recurrence. Finally, clays and sandstones are deposited alternately to a considerable thickness. The entire formation has been metamorphosed, folded, and traversed by several intrusive granite outcrops (Figure-1).

The Damagaram Mounio massifs appear on the northern side as a barrier against which cretaceous deposits accumulate, while on the other side they dip slowly southward and eastward beneath the infill of the Lake Chad basin. In the West and Southwest, geological formations are dominated by ferruginous sandstones with termite mound facies of the continental hamadian and the continental terminal (Figure-1).

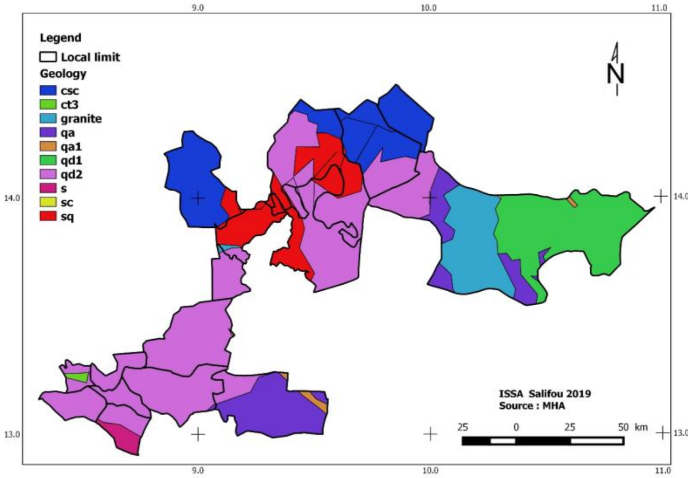

Figure-1: Geological map of the study area.

Table-2 provides an explanation of the legend for the geology of the area.

Table-1: Explanatory table of geology.

csc	Continental Hamadien
ct3	Clayey sandstone of middle Niger
granite	Granite
qa	Alluvial deposits with fine gravel forming sandy regs
qa1	Old alluvial deposits with pebbles and old terraces of Ténéré and Tamesna
qd1	Old erg with non-oriented dunes
qd2	Old erg with transversal dunes
s	Tafourfouzete, Serchouf (Leptynites), Azanguerene (Gneiss, migmatites) and Differentiated Suggarian formations
sc	Mica schists, cipolines, pargasite gneiss etc …
sq	Quartzites, schists

Data collecting: During this study, fifty two (52) water samples were collected and analysed from 13 boreholes (Figure-2). The sampled stations were grouped into two (2) types of including human-powered boreholes and mini dirking water supply.

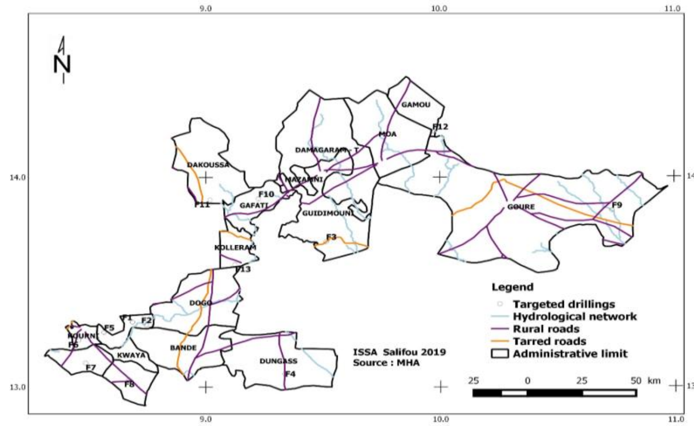

Figure-2: Distribution map of studied boreholes (F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F13).

Water samples were collected for physicochemical analysis according to standard methods L-Barres[12]. Before sampling, boreholes's waters were drained on site one (1) to two (2) minutes because they are continuously being used.

Physicochemical and chemical parameters followed during this study were analysed at the regional directorate of hydraulic and sanitation of Zinder (DRHZ) and the Nigerien Water Company (NDE) laboratories.

Physical parameters such as water electrical conductivity, temperature and pH were measured in situ by potentiometry and/or electrometry using a pH-meter (wagtech WE 30200) and a conductivity meter (wagtech WE 30210). The cations such as sodium, potassium were analysed using a flame photometer (Jenway PFP7), while total, calcium and magnesium hardness, carbonates and bicarbonates were meseared by the use of a digital titrator. Then the calcium and magnésium ions were deduced simply by calculation. Colorimetry method was used to determine anions such as sulphate, nitrate, chloride, nitrite, and fluoride ions, as well as total iron, using spectrophotometers (DR 1900 and 2800).

Data processing and analysis: The Water Quality Index (WQI) was determined from physical and chemical parameters according to the following equation

$$WQI = \frac{\sum_{i=1}^{n} Q_i \cdot W_i}{\sum_{i=1}^{n} W_i}$$

With: Q_i: Quality assessment scale for each parameter; Wi: weight of each parameter according to its relative importance in the quality of drinking water.

Thus, according to the value of the WQI, the water quality classes and their different possible uses are given in Table-2.

Table-2: Water quality index, status and its possible usages.

Water Quality Index Level	Water Quality Status	Potential Uses
0-25	Excellent water quality	Dinking, irrigation and industry
26-50	Good water quality	Dinking, irrigation and industry
51-75	Poor water quality	Irrigation and industry
76-100	Very Poor water quality	Irrigation
>100	Unsuitable for drinking	Must be treated before using

The QGIS software, version 3.38, was used to generate the various maps. To determine the hydrochemical characteristics of the waters, Microsoft Excel, was used us to produce Schöeller-Berkaloff representations as binary diagrams. This method was used by Issa[4], Hounsinou[7] and Bensaoula[13].

Results and Discussion

Table-3 presents the water quality indices. These results show that 84.6% of the borehole had excellent water quality while 15.4% were at good water quality.

Although the water was found as generally good according to the water quality index (WQI), excessive nitrate pollution was observed in 23.1% of the boreholes, making these waters unsuitable for human drinking.

Table-3: Water quality index (WQI) values for the sampled boreholes.

Boreholes	Water quality index (WQI)
F2	5,69087692
F3	9,55711188
F4	9,58316983
F11	10,0137802
F7	10,8896036
F1	11,0427894
F10	11,1456081
F13	11,6698469
F5	14,4487384
F8	15,1745985
F6	15,9586112
F9	27,9738334
F12	48,7148757

The Figure-3 to 15 shows the plots of the Schöeller Berkaloff diagram established from the major ions of the borehole waters.

The water of borehole F1 showed a calcium bicarbonate characteristic (Figure-3).

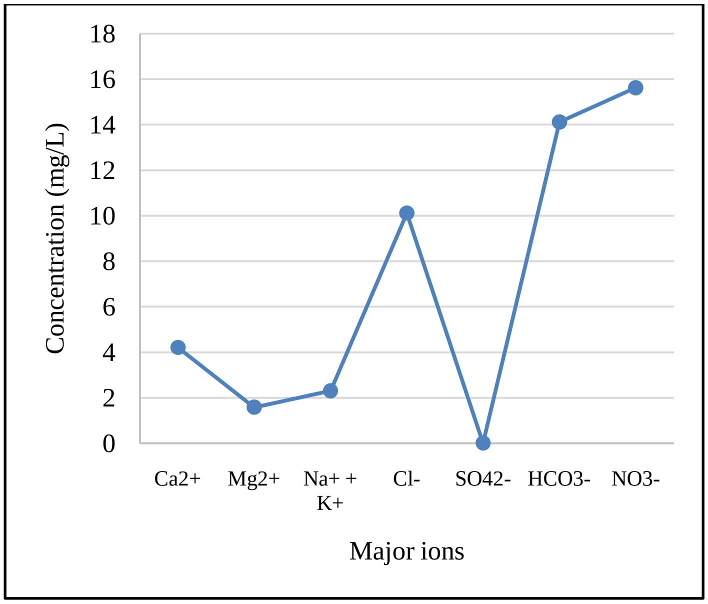

Figure-3: Schöeller-Berkaloff diagram of major ions in borehole F1's waters.

The water of borehole F2 had a calcium bicarbonate characteristic (Figure-4).

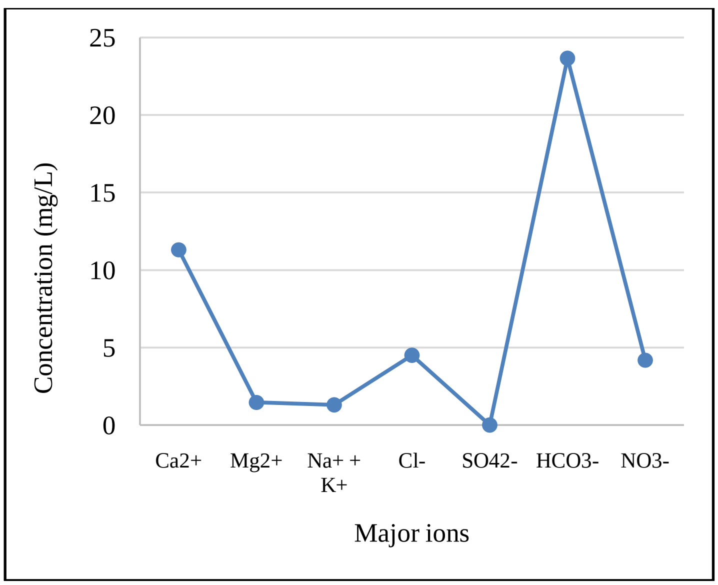

Figure-4: Schöeller-Berkaloff diagram of major ions in borehole F2's waters.

The water of borehole F3 indicated a calcium bicarbonate characteristic (Figure-5).

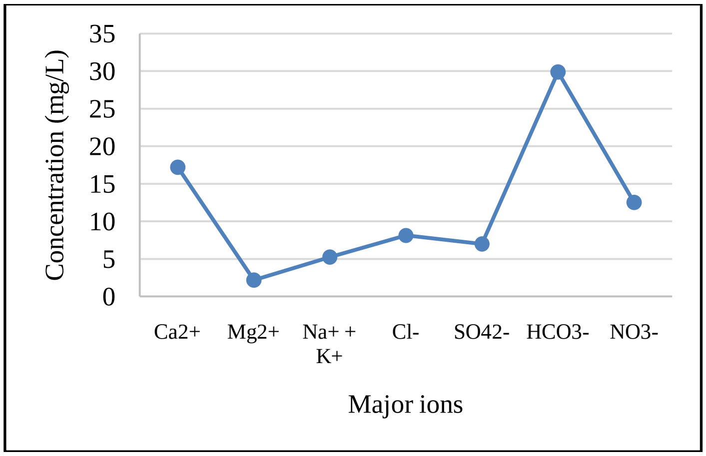

Figure-5: Schöeller-Berkaloff diagram of major ions in borehole F3's waters.

The water of borehole F4 had a calcium bicarbonate characteristic (Figure-6).

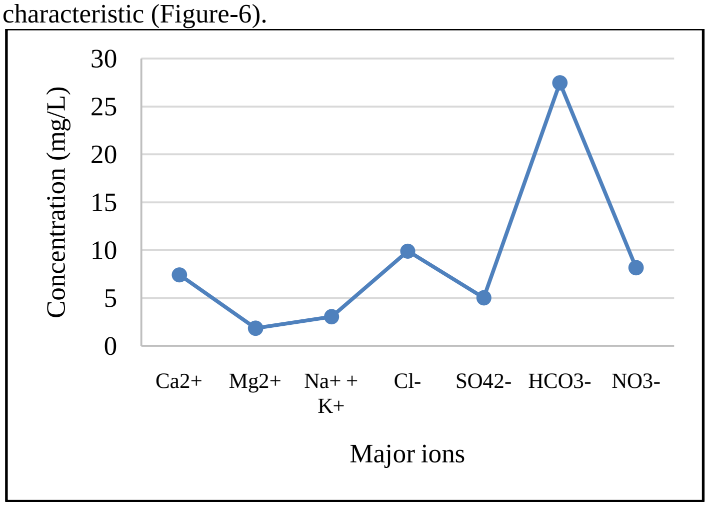

Figure-6: Schöeller-Berkaloff diagram of major ions in borehole F4's waters.

The water of borehole F5 showed a calcium chloride characteristic (Figure-7).

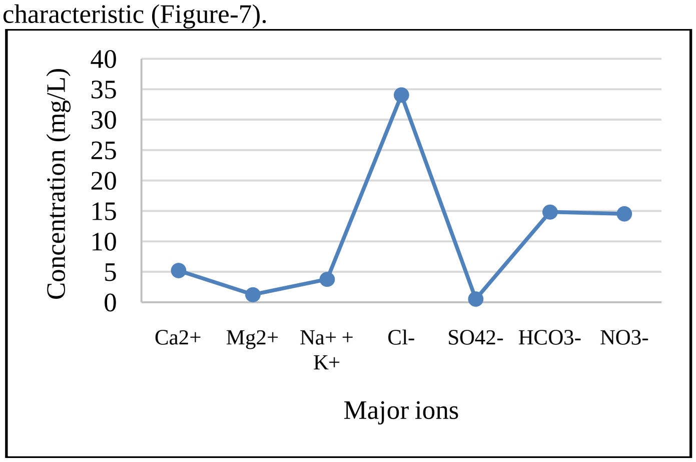

Figure-7: Schöeller-Berkaloff diagram of major ions in borehole F5's waters.

The water of borehole F6 indicated a sodium potassium bicarbonate characteristic, with occurrence of nitrate ions (Figure-8).

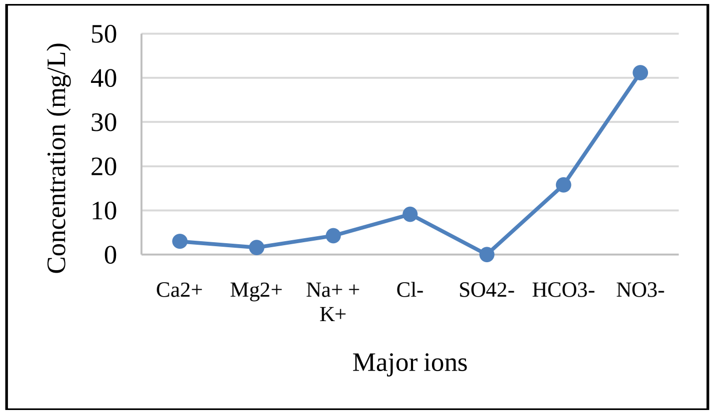

Figure-8: Schöeller-Berkaloff diagram of major ions in borehole F6's waters.

The water of borehole F7 showed calcium bicarbonate characteristic, with the occurrence of a chloride pole (Figure-9).

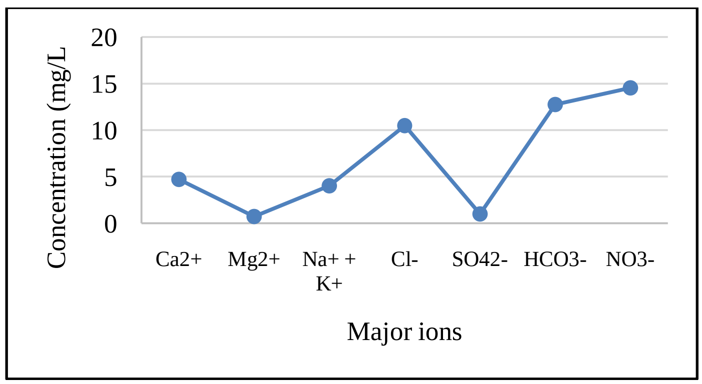

Figure-9: Schöeller-Berkaloff diagram of major ions in borehole F7's waters.

The water of borehole F8 had a calcium chloride characteristic, with net nitrate pollution (Figure-10).

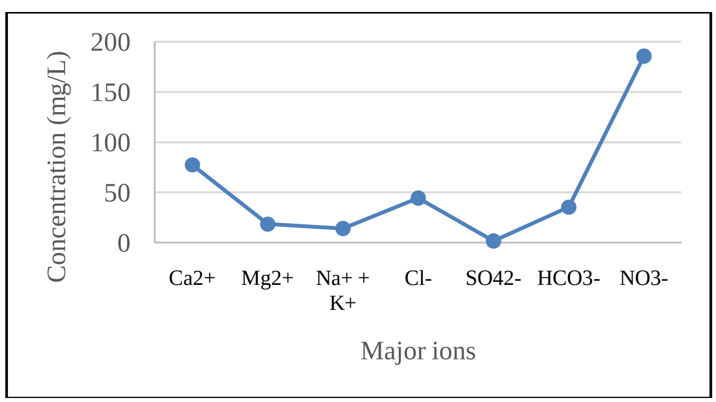

Figure-10: Schöeller-Berkaloff diagram of major ions in borehole F8's waters.

The water of borehole F9 indicated a sodium potassium bicarbonate characteristic (Figure-11).

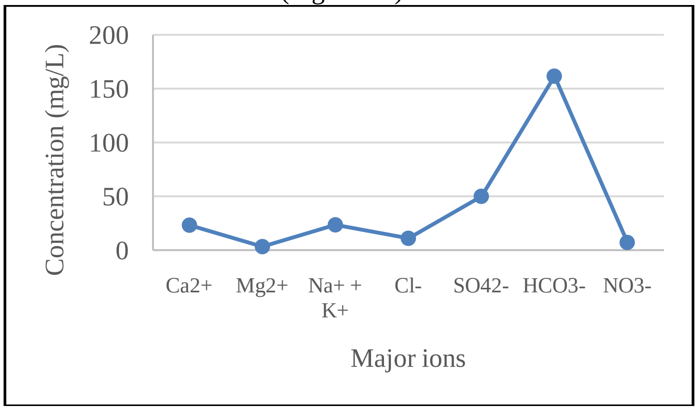

Figure-11: Schöeller-Berkaloff diagram of major ions in borehole F9's waters.

The water of borehole F10 showed a calcium bicarbonate characteristic (Figure-12).

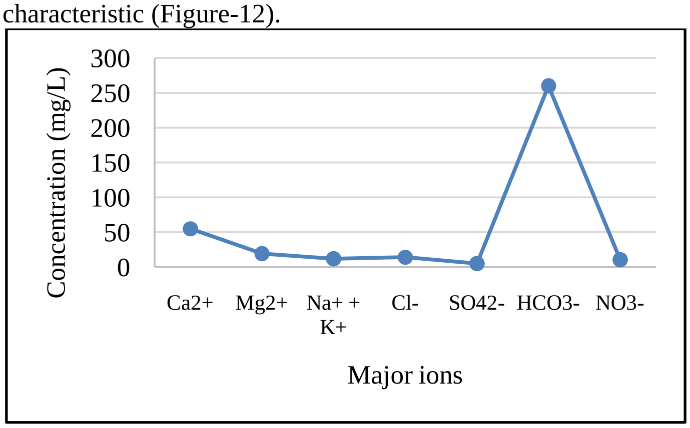

Figure-12: Schöeller-Berkaloff diagram of major ions in borehole F10's waters.

The water of borehole F11 showed calcium bicarbonate characteristic with an occurrence of net nitrate pollution (Figure-13).

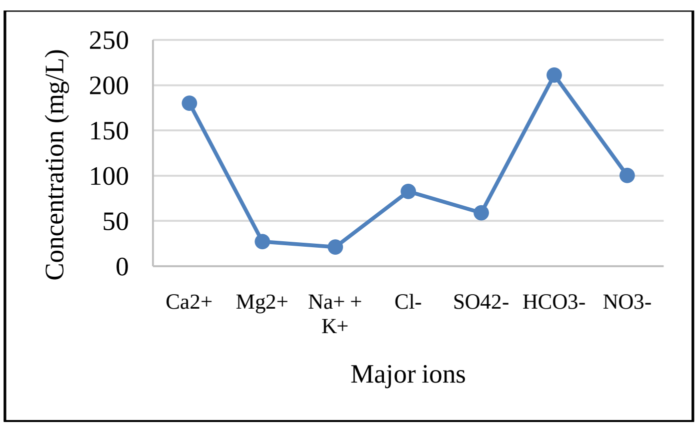

Figure-13: Schöeller-Berkaloff diagram of major ions in borehole F11's waters.

The water of borehole F12 showed a sodium potassium bicarbonate characteristic with occurrence of sulfate and nitrate pollutions and a chloride pole (Figure-14).

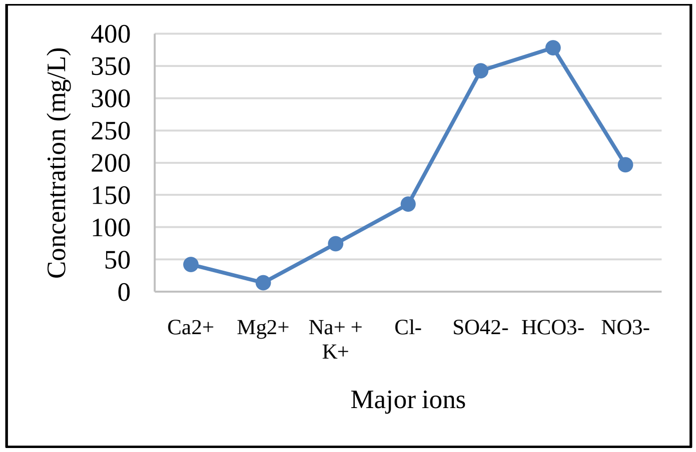

Figure-14: Schöeller-Berkaloff diagram of major ions in borehole F12's waters.

The water of borehole F13 indicated a calcium bicarbonate characteristic (Figure-15).

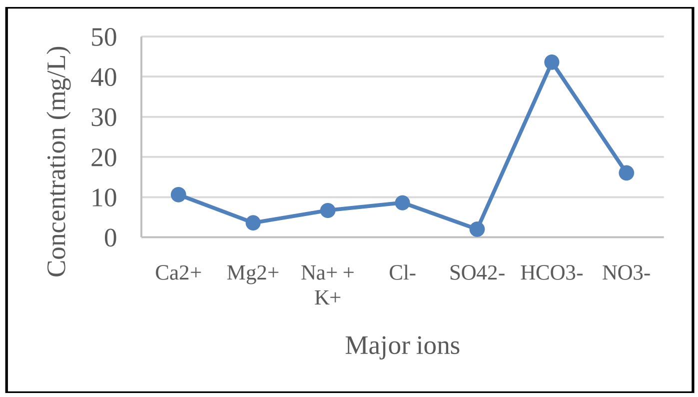

Figure-15: Schöeller-Berkaloff diagram of major ions in borehole F13's waters.

According to the obtained results from all the samples, the studied waters could be classified into three (3) facies as follows: waters with a calcium bicarbonate characteristic for 61.5% of the boreholes, waters with a sodium potassium bicarbonate characteristic for 23.1% of the boreholes and waters with a calcium chloride characteristic for 15.4% of the boreholes.

The bicarbonate pole could originates from the dissolution of carbonate minerals such as dolomite, which has been demonstrated in the area with saturation indices below zero[5,6]. This dissolution also the origin of the calcium pole. This bicarbonate pole has been observed in most of the waters of the studied boreholes and could be linked to the hydrolysis of CO_2 in the water[14]. This phenomenon could also lead to the dissolution of Ca^{2+}, Na^{+}, Mg^{2+}, and K^{+} ions.

The calcium pole could also resulted from the dissolution of carbonate and gypsum formations (Figure-16) which showed a saturation index below zero[5,6,15].

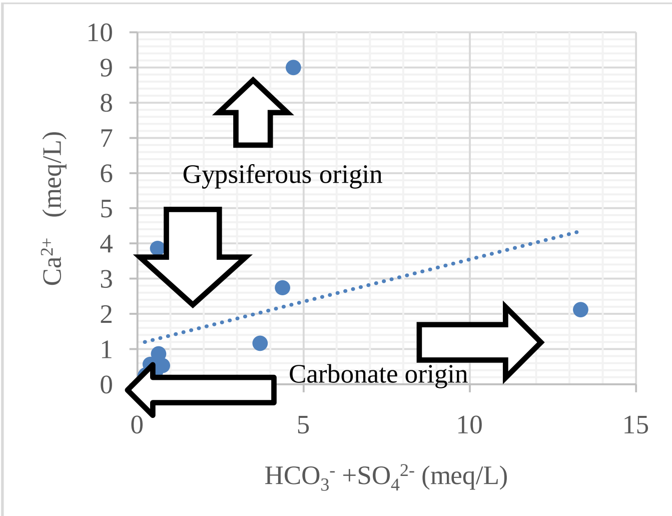

Figure-16: Origin of calcium and sulphate ions.

This pole could also be explained by the rise in basic exchange indices (BEI), leading to the massive release of calcium by the absorption complex during periods of low water (aquifer discharge). This release of calcium is accompanied by the fixation of sodium in waters (Figure-17).

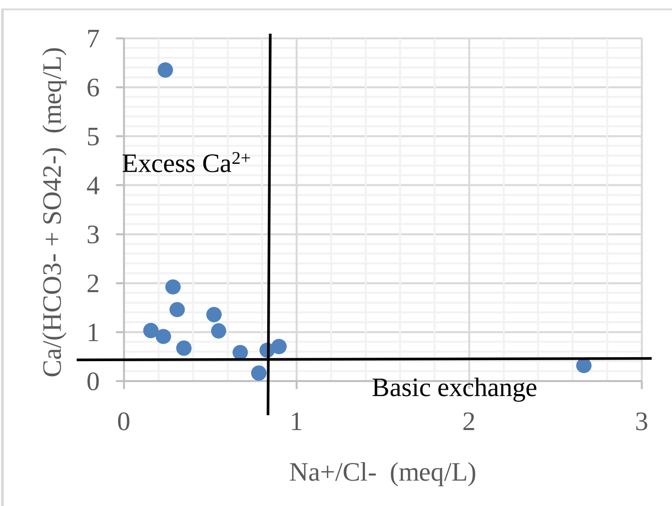

Figure-17: Origin of sodium and calcium ions.

The chloride, sodium, and potassium poles could be explained by transgressions of the formations of Lake Chad, which have a seabed. Indeed, according to Faure[11], this area was the center of epirogenous movements that led to the temporal and spatial displacement of sedimentation areas. The binary diagram plotting sodium and chloride ions (Figure-18) showed a correlation coefficient of 75.93%, proving that these ions could be originated from these deposits.

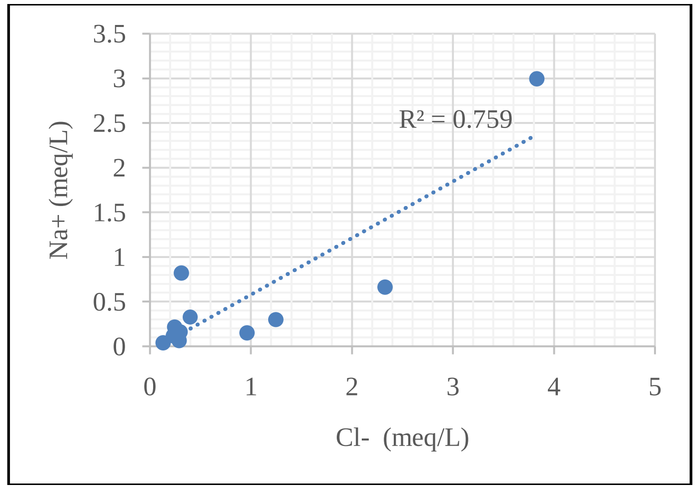

Figure-18: Origin of chloride and sodium ions.

The chloride pole could have also resulted from the silty fractions[6]. Indeed, the binary diagram that plotted sodium ions and chloride ions (Figure-19) showed an excess sodium ions that could be linked to these fractions.

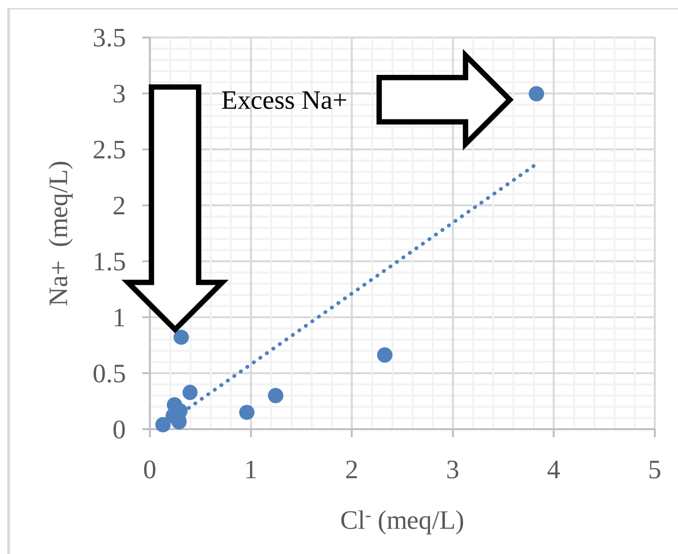

Figure-19: Origin of excess sodium ions.

From all the geological studied formations, the waters of 69.2% of boreholes showed nitrate pollution. This pollution may originate from the mineralization of organic matter in the basement rock formation[16] and the transfer of water to the other formations. It may also be linked to anthropogenic pollution that infiltrates rapidly through the Korama, which has a high permeability and low water depth. The occurrence of chlorides in the continental terminal and basement rock formations confirms the anthropogenic inputs. The high sulphate concentrations observed in the basement rock formation confirm the dissolution of gypsum-bearing formations found in the basement formation[16].

Conclusion

From the results of the hydrochemical analysis, the studied waters showed three (3) distinct facies: calcium bicarbonate for 61.5% of the boreholes, a potassium sodium bicarbonate for 23.1% of the boreholes and a calcium chloride of 15.4% of the boreholes. However, the bicarbonate pole was found in more than three-quarters of the boreholes. Also, it has been observed that even in the same aquifer, the water characteristics changed from one geological formation to another according to the spatial distribution of the sampling points. These variations highlight the importance of the hydrogeochemical processes that govern the mineralization of these waters.

Regarding water quality, the water quality index (WQI) indicated good water quality. However, in the three formations (Korama, Continental Terminal, and basement rock), a nitrate pollution was observed in over 50% of the boreholes, and 23.1% of these exhibiting nitrate concentrations exceeding drinking water standards. Also high chloride ion concentrations were recorded in continental terminal and basement rock while finally, high sulphate concentrations were noted in the basement rock formation. This pollution could be linked to water exchange between the formations, as well as to anthropogenic inputs from the surface due to the high permeability of the Korama formation.

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