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Use of Geological and Hydrogeochemical Data to Investigate Depressed Aquifers in the Southern Part of Lake Chad Basin (LCB), Cameroon

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Abstract Depressed aquifers highlighted on the Cameroon border of Lake Chad have not yet been closely studied. The purpose of this work is to improve the knowledge of these depressions by combining a dataset derived from geology and hydrochemistry. To do this, a field campaign was conducted. During this campaign, static levels and physicochemical parameters (pH, temperature, electrical conductivity and turbidity) were measured. Groundwater sampling was also carried out. This study shows that piezometric levels decrease from the edge to the central part of the depression, regardless of the flow line. Ph vary from 7.09 to 7.80, temperatures from 21.70°C to 24.50°C and conductivities from 181.66 µs/cm to 3446.66 µs/cm with the highest values in the depression; the mineralization is done within the aquifer. Two water facies: calcic/magnesic bicarbonate facies (87.5%) and sodic/potassic bicarbonate facies (12.5%) were noted. This facies change is due to substitutions within the clay formations and dissolution of evaporitic minerals. The different litho-stratigraphic logs show a heterogeneous aquifer of which the formations could not be correlated.

Keywords: *lake chad, cameroon, depressed aquifers, geology, hydrogeochemistry*

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1. Introduction

Natural enigmatic structures known as depressed aquifers were found in sub-Saharan Africa in the second half of the 20th century [1,2,3]. Piezometric depressions are defined as major hydrogeological anomalies, which are widespread in semi-arid sub-Saharan Africa, resulting in closed and concentric piezometric curves, and very pronounced hollows and dips attaining several tens of meters below the regional water table level [2,4,5,6].

Depressed aquifers were highlighted in Cameroon by [7] and [8]. Indeed, they measured static levels which allowed them to draw up a hydrogeological map of the Logone-Chari-Chad water table where depressions were observed. They attributed as a cause for these depressions a strong potential evapotranspiration induced by high annual temperatures, an extreme dryness of the atmosphere for low permeability aquifers with no or low recharge.

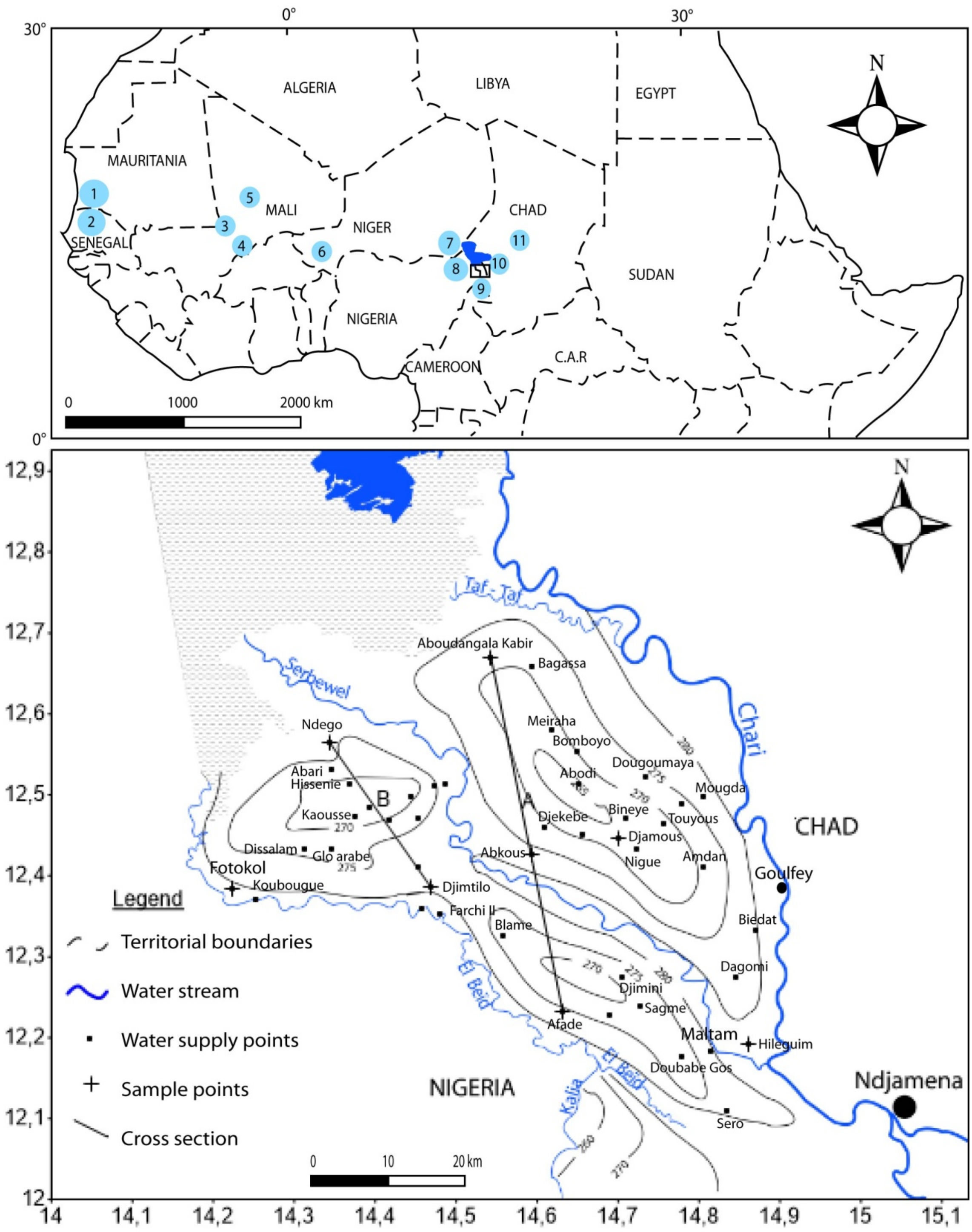
Several works have been devoted to the explanation of these enigmatic structures notably those of: [9-15]. But the origin of these structures is still debated in the scientific community.

Studies conducted in Cameroon by [6] lead to the conclusion that the Logone-Chari-Chad aquifer is a bilayer type. During this work, the north of the 12th parallel (southern border of Lake Chad) has not been studied.

The objective of this study is to improve the knowledge of the piezometric depressions observed in the north of the 12th parallel (Chari-Chad water table) using Geology and Hydrochemistry.

2. Geological and Hydrogeological Framework.

The study area is located in the Cameroonian part of the Chadian basin and covers approximately 4000 km^2 (Figure 1). It is bordered on the north by Lake Chad, on the west by El Beïd (temporary watercourse) and on the east by Chari (permanent watercourse) which is the main tributary of Lake Chad [16,17]. The water stream Serbewel which is a distributary of the Chari crosses the area in its central part and empties itself into the lake. The flow of these rivers depends on rainfall upstream of the basin.



Depressed aquifer of 1 : Trarza, 2 : Ferlo, 3 : Nara, 4 : Gondo, 5 : Azaouad, 6 : Kori of Dantiandou, 7 : Kadzell, 8 : Bornou, 9 : Yaérés, 10 : Chari-Baguirmi, 11 : Bahr El Ghazal.

Figure 1. Study area: location of measurements and sampling points and cross section.

The climate is Sudano-Sahelian with two distinct seasons (a dry season that runs from October to April and a rainy season from May to September). The annual average rainfall is of the order of 535mm. Mean annual temperatures range from 21.7°C to 28.7°C with April as the hottest month (33.8°C). Evaporation is 2993mm and the relative humidity varies from 25% to 60.16%.

Two types of soils dominate in the area, namely the vertisols and the Eutric fluvisols [18]. The first are clay soils, poorly drained, low permeable with large drying slots and high compactness in the dry season. In the rainy season, however, they fill up with water and thus reduce the permeability. The latter for their part, although in very small proportions, are soils little evolved input.

The area is in the Sudano-Sahelian floodplain characterized by indecisive and improbable slopes (0.10-0.16%). It consists of fluviatile delta, riverbank and dish [18]. The monotony of the relief is broken by hillocks attributed to the Sao populations.

The geology of the area shows quaternary formations consisting of lacustrine clays, clay and clay-loam alluvia and sand. These variations are due to oscillations between wet and dry periods during the Quaternary period [10]. Although no mineralogical description was found on the study area, except for clay minerals, quartz, micas, feldspars and finally calcite are the main minerals found in the sediments of the Lake Chad Basin [19]. The quaternary aquifer studied here has a thickness ranging from 50m to 70m and is based on the Tertiary clay deposits that constitute their bottom.

3. Methodology

Between 1954 and 1969, many water points were subjected to static level measurements. During these different works [7] and [8] drew up the hydrogeological map of the Logone-Chari-Chad aquifer. A field campaign was carried out and the water supply points used by these authors could not be found. That is why we cannot make a piezometric map similar to theirs. The water points used in this work were selected on the basis of field campaigns and using drilling fact sheets prepared for various urban and rural water projects (PUHV) between 1984 and 1990.

During this campaign, measurements were made in 57 boreholes and 6 wells in 46 villages in order to cover the center and the edge of the depressions along axes defined beforehand. The measurements made were static level, pH, temperature, conductivity and turbidity. Samples for chemical analyzes were also collected.

The laboratory analyzes concern the major elements consisting of cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (Cl^-, CO_3^{2-}, HCO_3^- and SO_4^{2-}). Nitrates were also determined and other parameters such as: turbidity, conductivity, pH and temperature were measured. The major elements were determined by spectrophotometry and colorimetry at the Laboratory of Chemical Engineering of the University Institute of Technology of the University of Ngaoundéré. The results are shown in Table 1.

4. Results and Discussion

4.1. Piezometric Study

The analysis of the piezometric measurements was made according to the three depressions observed in the study area. For each depression, two axes were defined and represent the main flow lines. In general, these axes are oriented N-S and W-E. In order to distinguish them, the depressions will be called the Chari-Serbewel depression for the one between the Chari and the Serbewel, the north and south depression for those between the Serbewel and El Beid.

Figure 2, Figure 3 and Figure 4 show the variation of the piezometric levels along the main flow lines.

The study of the variation of piezometric levels on the 03 depressions brings out the same information. The piezometric levels decrease from the edge to the central part of the depression, regardless of the flow line. The highest piezometric levels are located near watercourses, suggesting aquifer recharge through them [7]. This idea is supported by the average hydraulic gradients of about 1 ‰ towards the central part. These hydraulic gradients suggest a slow flow within the aquifer.

Table 1. Physico-chemical characteristics and chemical composition of groundwater samples

Localities	Longitude	Latitude	pH	T °C	E.C. (µs/cm)	Turbidity (NTU)	Ca^{2+}	Na^+	K^+	Mg^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	NO_3^-
Afade Sultanat	14.63102	12.23259	7.088	21.70	181.66	0.45	0.85	0.06	0.05	0.91	0.45	0.00	0.20	3.10	0.81
Aboudangala Kabir	14.54267	12.67040	7.089	22.06	1620.33	9.00	0.55	2.67	0.05	7.16	1.00	0.90	0.50	15.20	0.28
Ndego Milimi	14.34398	12.56371	7.091	23.46	3213.33	4.80	0.55	6.81	0.06	19.44	3.00	0.93	0.45	8.50	0.16
Fotokol lycée	14.22403	12.38465	7.800	24.40	633.00	0.28	0.30	0.87	0.05	0.50	0.35	0.52	0.35	6.05	0.08
Abkous Hamadie	14.59335	12.4269	7.090	24.30	712.00	34.40	0.40	1.14	0.05	3.40	0.75	0.33	0.30	7.30	0.28
Djimtilo	14.46831	12.38568	7.091	24.30	1235.66	1.36	3.14	1.41	0.06	2.28	0.85	2.05	0.40	6.35	0.28
Hileguim	14.86211	12.19226	7.089	24.36	1059.33	0.96	0.95	1.14	0.06	5.60	1.45	2.15	0.45	5.10	0.16
Djamous II	14.70105	12.44722	7.091	24.50	3446.66	0.40	0.50	4.92	0.06	9.90	1.45	0.66	0.25	10.50	0.40

Ions concentrations are in meq/L.

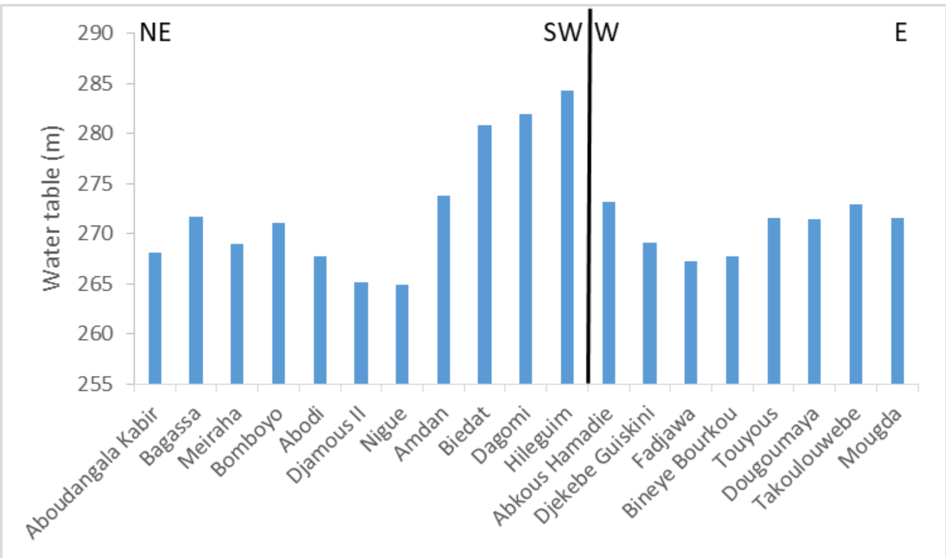


Figure 2. Histogram of the piezometric levels of the Chari-Serbewel depression

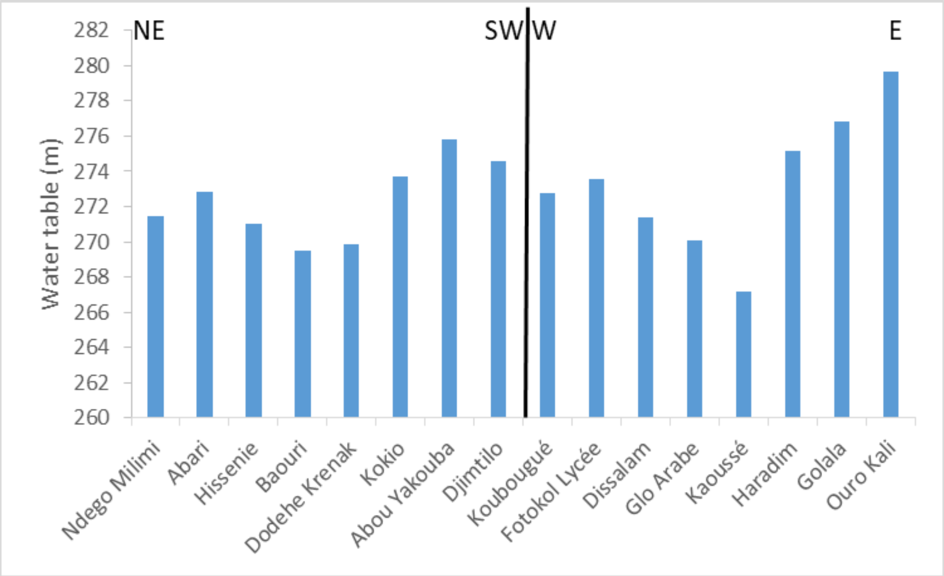


Figure 3. Histogram of piezometric levels of the northern depression

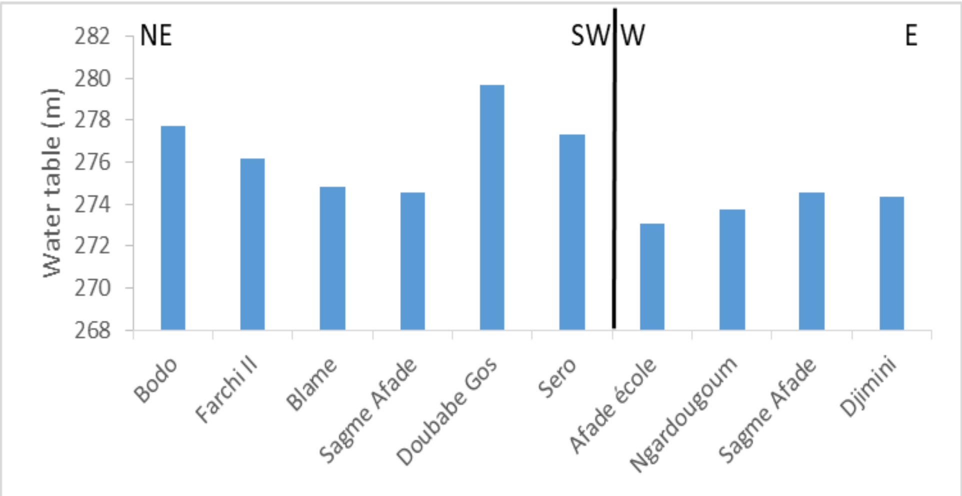


Figure 4. Histogram of piezometric levels of the southern depression

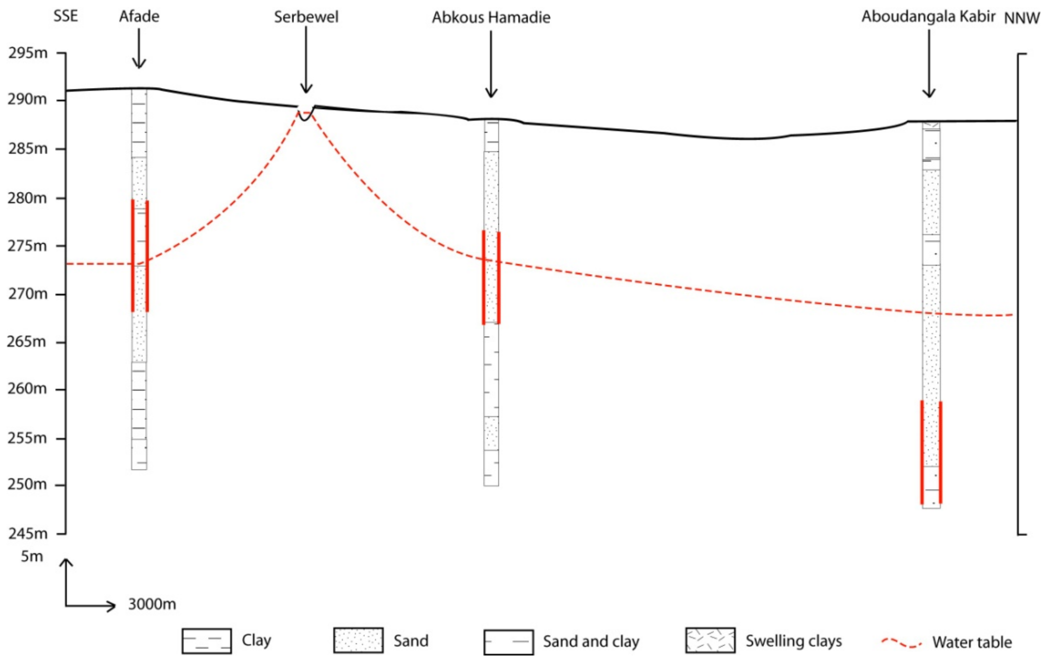


Figure 5. Litho-stratigraphic section of the Afade - Aboudangala Kabir axis (PUHV, 1984)

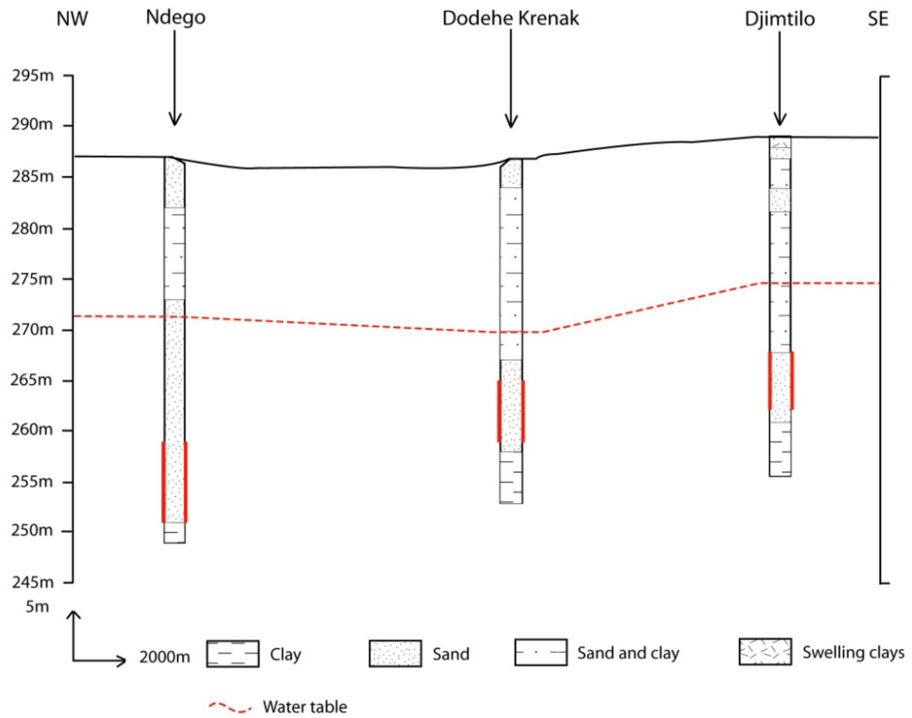


Figure 6. Litho-stratigraphic section of the Ndego - Djimtilo axis (PUHV, 1984)

4.2. Geological Study

The litho-stratigraphic logs of the boreholes realized during the village hydraulic campaigns made it possible to carry out correlation tests. Two axes oriented NNW - SSE (Figure 5) and NW - SE (Figure 6) were defined, based on available geological informations, to determine the aquifer geometry. The low density of information did not allow us to correlate them. Consequently, the locally described logs show sandy formations (aquifers) alternating with sand-clay and / or sandy-clay formations as observed by [14] in the Yaérés. This variation in formations and the impossibility of correlating the available informations raises doubt on the fact that this aquifer is homogeneous and should therefore be considered heterogeneous.

4.3. Hydrochemical Study

Ph vary from 7.09 to 7.80, temperatures from 21.70 °C to 24.50 °C and conductivities from 181.66 µs/cm to 3446.66 µs/cm with the highest values in the depression. Mineralization increases from edge to the center of depressions. [7] reported that low electrical conductivities are found in infiltration areas and drainage areas while high electrical conductivities correspond to areas of closed depressions. This finding was also made by [20] in the depressions of Bornou and Kadzell and by [21] in Chari-Baguirmi depression. This suggests that the mineralization processes occur within the aquifer [20,21].

The results of the chemical analyzes projected in the Piper diagram show 02 types of facies: a calcic / magnesic bicarbonate facies (87.5%) and a sodic/potassic bicarbonate facies (12.5%) (Figure 7). The same chemical facies were highlighted by [14] and by [22] in the Yaérés. The sodic / potassic bicarbonate facies, which is found at the Fotokol high school, could be explained by the substitution between calcium and sodium ions in the clay formations observed over the first ten meters.

Bivariate diagrams of ionic constituents have been developped (Na vs Cl, Ca vs Na, Ca vs Mg, Ca vs HCO_3, Ca vs SO_4) and are presented in Figure 8. In the same way, different ionic ratios have been calculated and present very variable values according to the concentrations of the elements.

Na / Cl ratios vary from 0.13 to 3.39 and there is a good correlation (r = 0.88) between the concentrations of these two elements (Figure 8a) which suggests a common origin (chloride salts, [23]). Nevertheless, because of the excess in Sodium (6/8), this ion has another origin [20,21,24].

Ca / Na ratios are between 0.08 and 14.17. There is no correlation between these two elements (Figure 8b) and an excess of Sodium (6/8); this could be related to ion exchange with the clay matrix. On the other hand, Ca / Na> 1 can originate from the dissolution of calcium carbonate and / or calcium sulphate minerals [20,24].

Ca / Mg ratios vary from 0.03 to 1.38. These two elements are not correlated (Figure 8c), so do not have a common origin. The excess of magnesium (7/8) observed could be due to the dissolution of minerals such as dolomite (Ca $Mg(CO_3)_2$) but other geochemical processes also contribute to the regulation of these elements, like isomorphous substitutions at the clay layer levels, $Ca^{2+} \leftrightarrow Mg^{2+}$ exchanges during precipitation or recrystallization reactions of calcite [21,25].

Ca / HCO_3 ratios are between 0.04 and 0.49; there is an excess of HCO_3. The lack of correlation between these elements (Figure 8d) highlights different origins. The evolution of the contents of these two elements is therefore not governed solely by the behavior of calcium carbonate minerals ($CaCO_3$). One of the possible origins of the excesses observed may be the alteration of calcic plagioclase as soon as surface water infiltrates [26]. Calcic plagioclase is the most easily altered silicate mineral. This reaction is accompanied by an increase in the contents of bicarbonates [27].

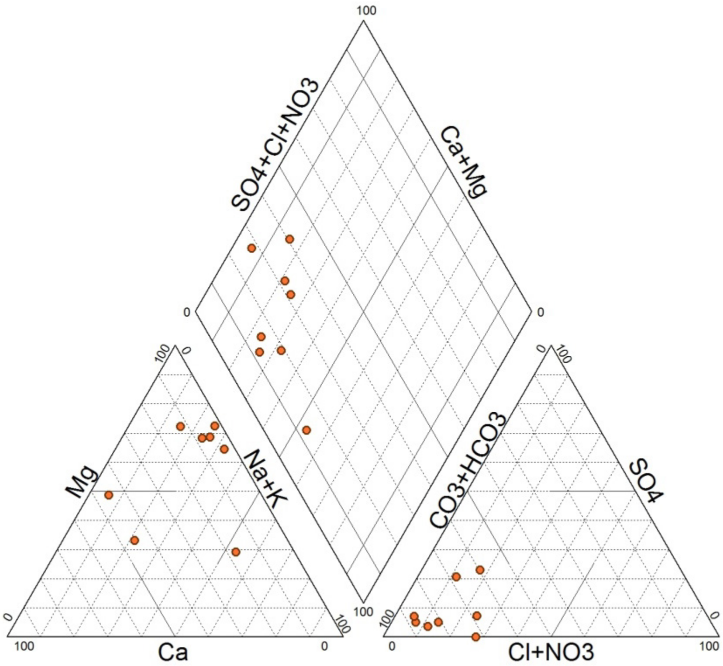


Figure 7. Piper Diagram of groundwater

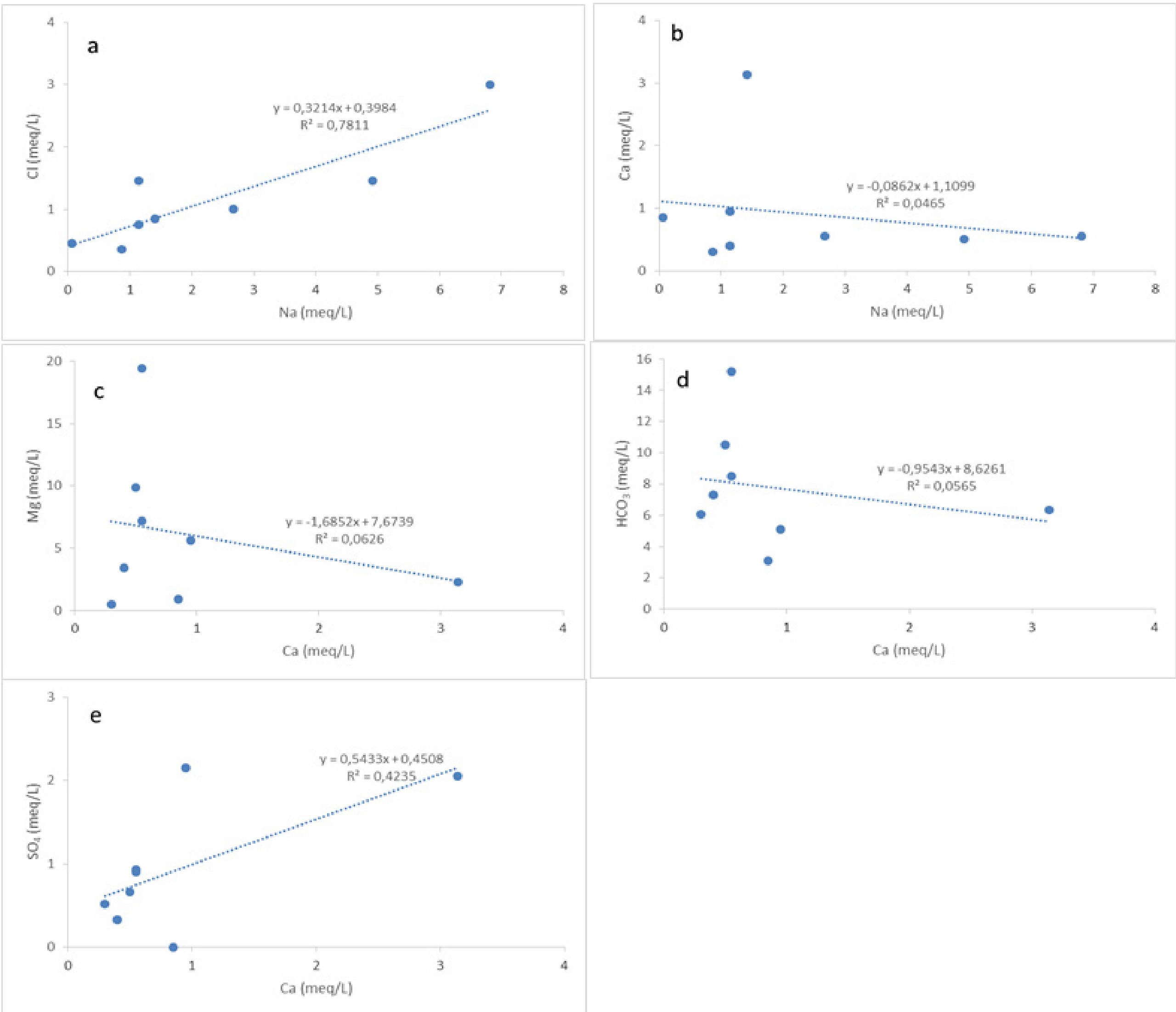


Figure 8. a) Na vs Cl, b) Na vs Ca, c) Ca vs Mg, d) Ca vs HCO_3, e) Ca vs SO_4

SO_4 / Ca range from 0.00 to 2.26. There is a good correlation (r = 0.65) between these elements (Figure 8e) which suggests a common origin. The excesses observed in Ca (3/8) can be due to the dissolution of calcium sulphate minerals, in particular gypsum ($CaSO_4$, $2H_2O$) and anhydrite ($CaSO_4$) [20,28] but the excesses in SO_4 (5/8) show that the dissolution of these elements is not solely the result of dissolution.

5. Conclusion

The study of the depressions observed at the southern edge of Lake Chad by Geology and hydrochemistry provided information on the origin of these depressions.

The piezometry which decreases from borders towards the central part of the depressions suggests a recharge through the rivers which border them. The weak hydraulic gradients show a very slow flow within the aquifer.

The geological study using available litho-stratigraphic logs shows a multi-layer aquifer where sandy levels separated by clay and / or sandy-clay formations are observed.

The measured conductivities evolve from the edge to the central part of the depression; the mineralization is done within the aquifer. The chemical data show 02 chemical facies: a calcic and / or magnesic bicarbonate facies which is the most represented and a sodium and / or potassium bicarbonate facies. This facies change is due to substitutions within the clay formations that bind calcium and release sodium, which is more soluble and dissolution of evaporitic minerals.

In order to better understand the functioning of these depressions, it would be wise to perform a geophysical study for instance Magnetic Resonance Sounding (MRS), an isotopic study using tritium and stable isotopes of water, a piezometric monitoring and finally carry out other chemical analyzes.

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