Original ResearchArticle

Physico-chemical quality of groundwater in the polders of Lake Chad: the case of the Bol-Bagassola polder

Abstract

Located southwest of Lake Chad (Bol-Bagassola), the study area is characterized by a Sahelian-type climate underlain by more recent sedimentary cover. The aim of this manuscript is to assess the overall impact of agricultural activities on groundwater quality in the polders (Bol and Bagassola), in order to gain a better understanding of agricultural pollution. To achieve this objective, a water sampling campaign was carried out to study hydrodynamics and hydrochemistry. As a result of this study, piezometric levels are not sufficiently heterogeneous. The pH is around neutral with an average of 7.68, and water temperatures vary between 25.3°C and 32.5°C. Conductivities ranged from 334µS/cm to 9800µS/cm, exceeding the maximum WHO/Chadstandards limit of 2500µS/cm. Most of the variables (chemical parameters) are below the drinking water quality limits defined by WHO/Chadstandards, with the exception of the open wells (P1, P2) at Malkoura, which show very high concentrations of potassium, sulfate, sodium, chloride, ammonium and magnesium, and the high iron signature observed in boreholes F9 and F12 at Talia. These variables (chemical parameters) enabled us to define the bicarbonate calcic and magnesian facies, followed by chloride sodium and potassium or sulfate sodium for the single F9 borehole at Malkoura. The predominance of bicarbonate facies can be explained by the dissolution of evaporites in the reservoir.

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Key words: Lake Chad, Bol-Bagassola, agricultural activities, water quality, Groundwater, Polder.

Introduction

Water is a vital and invaluable natural resource, and Chad is fortunate to be relatively well endowed with it (BRGM, 1994). The quality of this resource has greatly deteriorated, particularly in recent decades, due to pollution caused by agricultural activities (Bouabbache et al., 2015; Djoret and Favreau, 2014).

According to the FAO, agriculture is the most water-intensive economic activity, accounting for almost 70% of all water mobilized from rivers, lakes and groundwater worldwide, and up to 95% in developing countries (Keddal and N'dri, 2008), and is currently a source of water pollution through the use of fertilizers, pesticides and livestock effluents. This water contamination leads to the loss or restriction of many uses, such as drinking water supply and water sports activities for surface waters, and jeopardizes groundwater use in terms of quality throughout the world. It also leads to a significant increase in the costs of making these waters drinkable and countering the risks to human health (Deubalbe et al., 2021).

Groundwater management is a matter of growing concern, and will have to be done properly if agricultural activities are not to generate pollution that can harm water resources and aquatic ecosystems. This situation is exacerbated in Chad, with its arid and semi-arid climate, where overexploitation, water evaporation and anthropogenic pollution pose unprecedented allocation and management problems. Ensuring groundwater quality adapted to human and ecological needs is therefore an important aspect of integrated environmental management and sustainable development.

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For some years now, the polders of Lake Chad have been exploited by the Société du Lac Tchad (SODELAC) and *Agence Nationale de Développement Rural* (ANADER) for agricultural activities, and they also support farmers. To get a better harvest or yield, farmers use chemical fertilizers and pesticides. These products have harmful and degrading effects on the environment in general, and water resources in particular.

Moreover, the aquifer in the area is shallow and previous studies (Bouchez et al., 2019, Mahamat Nour et al., 2022) have shown that this aquifer is recharged at the edges of the Lake. Chemical fertilizers and pesticides used by farmers in the Lake Chad polder can infiltrate with the recharging water, polluting the aquifer. To date, very few studies have been carried out in the area to understand the impact of these products on the groundwater resource, hence the purpose of this work. The main objective is to diagnose the current state of groundwater quality in the lake polder, and more specifically in the Bol - Bagassola sector.

In this context, this work presents the following scheme... [place according to your style as you structured the article] ...to carry out a diagnostic study of groundwater quality in the Bol-Bagassola sector.

1. Study site

1.1. Location, geomorphology and soils

1.1.1. Location

The study area is located in the Lake Chad province. The study area is small, covering only part of the Mamdi (Bol) and Kaya (Baga-sola) departments. It lies to the south-east of the Lac province, between latitudes 13°31' and 13°35' N and longitudes 14°25' and 14°36' E (Fig.1).

1.1.2. Geomorphology

The Lac province is a lowland (polder) characterized by alternating aeolian sand dunes. These sand dunes are found throughout the province and around the Lac border, with a considerable altitude ranging from 275 to 312 m (Fig. 1). Slopes are much steeper in the lowlands and polders (Carmouze et al., 1978).

1.1.3. Soils

Polder soils develop on formations corresponding to a recent lacustrine series, whose deposition began 9,000 years before present (Rieu, 1995). Polder soils have high agricultural potential, and the region is considered both the granary and the orchard of the country. The polder zone groups together brown steppe soils and hydromorphic soils where soils on lacustrine alluvium, clayey-sandy soils, alluvial soils, beige sandy to sandy-clay soils and tropical black clays are distinguished (Adoum et al., 2017).

1.2 Climatic description

The climate of the study area is Sahelian. Rainfall lasts for four (4) months (June-September). The heaviest rains are generally recorded in August, with an average monthly rainfall of around 135mm (Fig. 2). Rainfall is heterogeneous over time. The average annual rainfall over 22 years of observation is 257mm, with some inter-annual variations, the extremes of which are 102.8mm and 417.5mm (Fig.3). The annual temperature varies from 38°C to 41°C, with an annual average of around 37°C (Fig. 2).

The umbro-thermal curve shows that two months of the year (July and August) are considered wet (Fig. 2).

1.3 Hydrogeology and hydrology

The hydrogeology of Chad in general and that of the Lake Basin in particular is known from the work of (Schneider and Wolff, 1992) and other researchers such as (Cheverry, 1974; Abderamane et al., 2013), who show the succession of different geological layers (sand, sandstone) in the basin's aquifers.

The Quaternary aquifer is the main regional transboundary aquifer, characterized by different depositional systems. The aquifers are free, captive or semi-captive depending on their relative position and the occurrence of clay layers (IAEA, 1993).

Hydrologically, the Lake Chad Basin is an endoreic basin, but one in which the bulk of the hydrographic system flows to a low point: Lake Chad, located at an altitude of around 280 m (Bouchez et al., 2016, Djoret, 2000; IAEA, 1993). It is fed by the Chari-Logone, which rises in the mountainous areas of the Central African Republic and Cameroon (Lemoalle and Magrin, 2014). It collects inflows from streams in the southern part of the watershed. The Komadougou Yobe, El Beïd and various small streams from Nigeria and Cameroon have very low flows compared with the Chari-Logone (Olivry et al., 1996; Lemoalle and Magrin, 2014).

2. Data collection and analysis methods

Fieldwork was carried out from 06 to 13 March 2023. Firstly, a survey was carried out among the population to find out overall about the methods developed for agriculture and the types of fertilizers and pesticides used.

A total of 15 points (wells and boreholes) were surveyed, and statistical levels were measured using an electric probe (Fig. 1). Physico-chemical parameters (pH, temperature and electrical conductivity) were measured in situ using multi-parameters.

Water samples (wells and boreholes) were taken for possible chemical analysis. Samples for chemical analysis were taken in 750 ml vials. These were rinsed at least three times with the water to be sampled, and the bottles were filled to the brim before being hermetically sealed to prevent air bubbles. The samples were then placed in a cooler to be maintained at a temperature of 4°C before being transported to the laboratory.

Chemical analyses were carried out at the Hydro-Géosciences et Réservoirs (LHGR) laboratory of the University of N'Djaména and the Laboratoire Nationale de l'Eau (LNE) of the Ministry of Water and Sanitation. Analytical methods vary according to the chemical elements. HCO3- and Cl^- were determined using the volumetric method, Na^+, K^+, Ca^{2+}, Mg^{2+}, Mn^{2+}, NH_4^+ were determined using the DR7100 Photometer and SO_4^{2-}, NO_3^- by spectrometry (the DR3900).

3. Results and discussion

3.1 Survey results

The survey revealed that, of the 58 farmers interviewed, 32 (55%) said that rainfed, market gardening and irrigated farming were the traditional types of farming practised in the study area. Soils are rich, so farmers use only chemical fertilizers in the more fertile polders, and much more in the Kaya department. Pesticides (herbicides and insecticides) are used throughout the province, with the aim of eradicating wild grasses toxic to the crop and eliminating insect pests. Soil salinization remains a major scourge and has a negative impact on the agricultural sector in this area.

3.2. Static level of structures

The static level is defined as the water level not subject to pumping, injection or undisturbed recharge. It is the water level at equilibrium in boreholes or wells. In the study area, static levels vary between 2.13m and 16.44m at water points, with an average of 11.26m (Fig. 4).

3.3. Physico-chemical parameters of sampled water

The temperature of groundwater in the study area often varies between 32.5°C and 25.3°C, with an average of 30.34°C in the water points studied (Fig. 5a). The highest temperature measured in the field was at Melea F6 (32.5°C) and the lowest at Malkoura P2 (25.3°C). The temperature of these water points is close to the ambient air temperature, reflecting a thermal equilibrium between the atmosphere and the surface water table (30m) in Sahelian zones (Ngounou Ngatcha, 1993).

pH is one of the physico-chemical parameters that measures the concentration of H+ protons in water. It provides information on the acidity and alkalinity of water. In the study area, groundwater pH ranges from 7.32 to 8.72, with an average of 7.68 (Fig. 5b). The pH of the study area is generally basic (> 7). Referring to the WHO/Chad standard (6.5≤ pH ≤ 9) for drinking water, we note that all water points are fit for consumption.

Electrical conductivities range from 334 to 9800 µs/cm, with an average of 1657.67 µs/cm (Figure 5c). These very high values are thought to be due to the dissolution of salts by groundwater flow and the leaching of chemical substances or fertilizers (animal excreta), as well as the residence time of water in the reservoir, as confirmed by (Schneider, 1967; Djoret and Favreau, 2014). The water analyzed at the water points was mineralized, with values ranging from 334 µs/cm to 9800 µs/cm. All but two (2) samples (Malkoura P1, P2) exceed the maximum value of the WHO/Chad standard set at 2,500 µs/cm. These very high values would be due to the dissolution of salts by the flow of the water table along its gradient according to the piezometric map of the study area and by the leaching of chemical substances or fertilizers (animal excreta) and also the residence time of water in the reservoir as confirmed by (Schneider, 1967; Djoret and Favreau, 2014).

3.4. Descriptive analysis of water chemistry

Calcium (Ca^{2+}) concentrations are variable and generally low compared with the WHO/Chad standard (≤ 200 mg/l). They range from 15.2 mg/l (Mar F7) to 168 mg/l (Malkoura P1), with an average of 39.72 mg/l.

Magnesium levels were lowest at Nguelea F8 (0.778 mg/l) and highest at Malkoura P2 (201.2 mg/l) (Table 1). This high level, which exceeds the maximum WHO/Chad limit (≤ 50 mg/l), is thought to be due to leaching from the carbonate layers and anthropogenic sources, as asserted by (Djoret, 2000).

The spatial distribution of potassium levels is very heterogeneous. The highest levels (2 mg/l (Malkoura F9) and 21 mg/l (Malkoura P2) with an average of 5.26 mg/l) exceed the WHO/Chad standard for drinking water, set at ≤ 12 mg/l. This high level of these ions could be the result of evaporation from the water table or ionic exchanges with calcium or magnesium ions from clays present in the environment, as well as leaching from animal excrement.

Sodium (Na+) ranges from 16 mg/l (Mar F7) to 897 mg/l (Malkoura P2), with an average of 224.58 mg/l (Table 1). Chloride (Cl^-) ranges from 17 mg/l (Mar F7) to 410 mg/l (Malkoura P2). Sodium and chloride are elements whose concentrations can vary from one water to another. The highest sodium and chloride values are found at Malkoura P2, with 897 mg/l and 410 mg/l respectively, which are above the WHO/Chad standard set at $Na^+ \leq 200$ and $Cl^- \leq 250$). The origin of these high concentrations in the water would be linked mainly to the leaching of evaporitic deposits, precipitation between alluvial phases of the detritic series as stated (Schneider, 1967). This is due to the phenomena of leaching, evaporation and base exchange, as well as to the dissolution of saliferous minerals.

3.5. Water chemistry

The results of the chemical analyses were plotted on a Piper diagram to define the chemical composition of the analyzed waters in terms of quality (Fig. 6). Projection of the chemical analysis results in this diagram shows that the groundwater in the study area is generally of the Calcium-magnesium bicarbonate (98%), with a slight tendency to migrate towards the chloride-sulfate-calcium-magnesium pole (P3 and P1), with the exception of the Malkoura F9 water point, which has sodium-potassium chloride or sodium-sulfate facies (2%). This same facies was found in the N'Djamena nappe during (Djoret, 2000) studies on water recharge. This confirms that the Quaternary nappe is more or less composed of the same geological bedrock.

3.6. Correlation between chemical elements

3.6.1. Pearson correlation matrix

Linear correlations between certain relevant chemical elements can be used to investigate the origin of mineralization by assessing the degrees of dependence between the various parameters concerned. The assessment is made using correlation coefficients determined by statistical calculations. The correlation between two parameters is all the more significant when the correlation coefficient R is close to the value 1. Correlations were thus established between all the major elements taken in pairs, resulting in the binary correlation diagrams below. Correlation analysis shows in Table 1 that several variables (physico-chemical characteristics) in the study area correlate strongly with each other. Almost all major ions taken in pairs have a strong positive correlation. Chloride, bicarbonate, magnesium, nitrate, sulfate, potassium, sodium and ammonium are strongly correlated with electrical conductivity. This suggests that these variables are more or less of the same origin, and that this is due to high mineralization. Nitrate and ammonium are correlated with each other and also with magnesium, sodium and potassium. This link could be due to anthropogenic inputs (animal excrement, pesticides or even chemical fertilizers) to the water table through infiltration or leaching. On the other hand, only calcium and iron either don't correlate or correlate very weakly, which could be explained by the fact that they have a different origin than the elements.

3.6.2. Na^+ vs Cl- ratio

The Na+/cl- ratio result correlates well with the correlation coefficient (R2= 0.89) (Fig. 7). The origin of these ions would be due to the dissolution of salt, otherwise known as Halite (NaCl), which is a rock formed by the chemical precipitation of elements dissolved in water during a supersaturated solution. No mention has ever been made of the presence of salts in the Lake Chad basin. The presence of these elements could be due to the amendment of chemical fertilizers in the lake polder (Carmouze, 1976).

3.6.3. Na^{+}+K^{+}vs NO_3^{-}

Referring to the Na^{+}+ K+/NO_3^{-} ratio figure below (Fig. 8), we can say that these ions correlate perfectly with each other with (R2=0.93) although they have slightly different sources or origins.

As we said earlier, the presence of sodium (Na^{+}) is due to the dissolution of salt when it precipitates, whereas the presence of potassium (K^{+}) and nitrate (NO_3^{-}) in water can be explained by anthropogenic activities (livestock breeding, agriculture) or by leaching or infiltration. Water can carry animal excrement, pesticides and chemical fertilizers in open wells and boreholes.

3.7. Spatial distribution of chemical elements

Bicarbonate (HCO_3^{-}) content ranges from 56.12 mg/l (Mar F7) to 1073.6 mg/l (Malkoura P2), with an average of 73.03 mg/l. Its origin is thought to be due to evaporitic dissolution and the action of CO_2 from meteoric waters and soil. Analysis of bicarbonate (HCO_3^{-}) content reveals a heterogeneous spatial distribution of levels (Fig.9).

The minimum sulfate content is 6 mg/l at Mar F7 and the maximum is 1219 mg/l at Malkoura P2 (Fig. 10). The increase in this concentration (Malkoura P2) could probably be explained either by soil leaching in the polders, by leaching from the evaporitic layers of the geological bedrock or by the dissolution of gypsum ($CaSO_4$) (Abderamane, 2012).

Nitrate concentrations analyzed are heterogeneous and variable, with a maximum value of 46 mg/l at Malkoura. Its content is below the set standard (≤ 50 mg/l). Nitrates have an anthropogenic origin (use of fertilizers or leaching of animal excrements).

3.8. Overall groundwater quality in the area

Assessment of groundwater quality is based on the study and interpretation of the results of physico-chemical parameters, which are indicators of pollution.

Electrical conductivity and chloride ion concentrations provide information on mineralogical water quality, while nitrates and other parameters are the main indicators of groundwater pollution.

According to Table 2, the groundwater in the samples (F1, F2, F3, F4, F5, F6, F7, F8, F9, P3, F10, F11 and F12) is generally of good quality for all parameters, with the exception of F9 (Malkoura) and F12 (Talia), where we note a very high iron signature (0.5) above the WHO/Chad standard (0.3). This high level is likely to be due either to the lithology of the environment or to the pipes, and could adversely affect the quality of the water.

Samples P1 and P2 have poor water quality due to very high levels of certain parameters exceeding the maximum limit of the WHO/Chad standard, such as electrical conductivity, iron, sodium, potassium and ammonium. These high levels could be explained by various sources, including the dissolution of evaporites, saliferous minerals and the leaching of animal excrement. They could also be explained by the low piezometry of well P2.

Conclusion

The aim of this study was to assess the impact of agricultural activities on groundwater quality in the Bol and Bagassola polders. The area has a sub-arid to arid climate with two (2) seasons: a rainy season of four (4) months and a dry season of eight (8) months.

It should also be noted that several methods were used to collect the data. A total of fifteen (15) water points (boreholes and wells) were sampled. Physico-chemical parameters were measured in situ. As a result of this study, piezometric levels are not sufficiently heterogeneous. The pH is around neutral with an average of 7.68, and water temperatures vary between 25.3°C and 32.5°C. Conductivities ranged from 334µS/cm to 9800µS/cm, exceeding the maximum WHO/Chad limit of 2500µS/cm. Most of the variables (chemical parameters) are below the drinking water quality limits defined by WHO/Chad, with the exception of the open wells (P1, P2) at Malkoura, which show very high concentrations of potassium, sulphate, sodium, chloride, ammonium and magnesium, not to mention the high iron signature in boreholes F9 and F12 at Talia. These variables (chemical parameters) enabled us to define the calcic-magnesium bicarbonate facies, followed by sodium-potassium chloride or sodium-sulfate facies for Malkoura's sole F9 borehole.

Please, place the percentage error of the measurements mentioned in the conclusion.

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Figures and tables

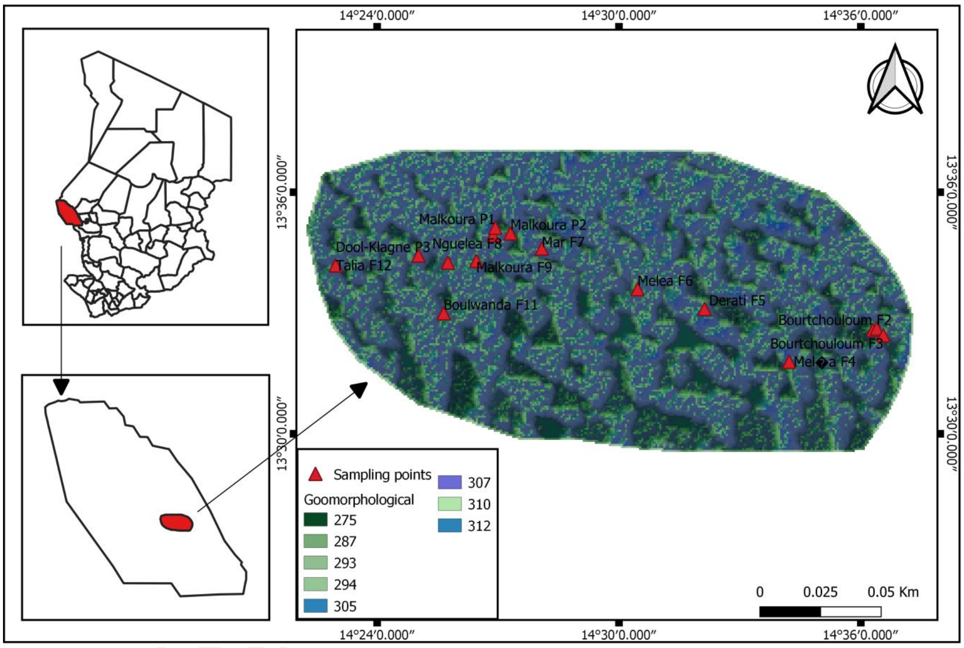

Figure 1. Location map of the study area(Enter the name of the area). ~~Red dots~~Triangle shape red dots represent sampling points.

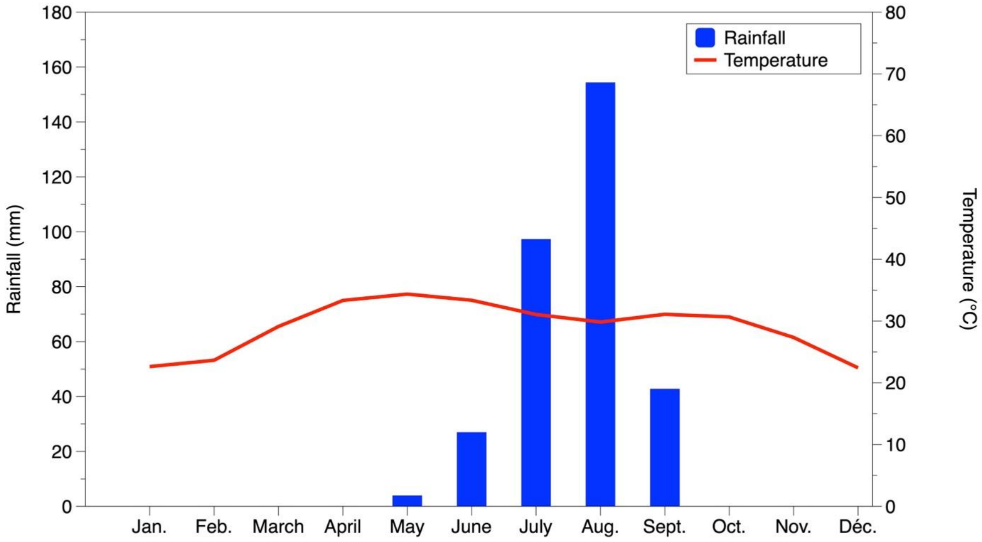

Figure 2. Umbro-thermal diagram of Bol station data from 2000-2016

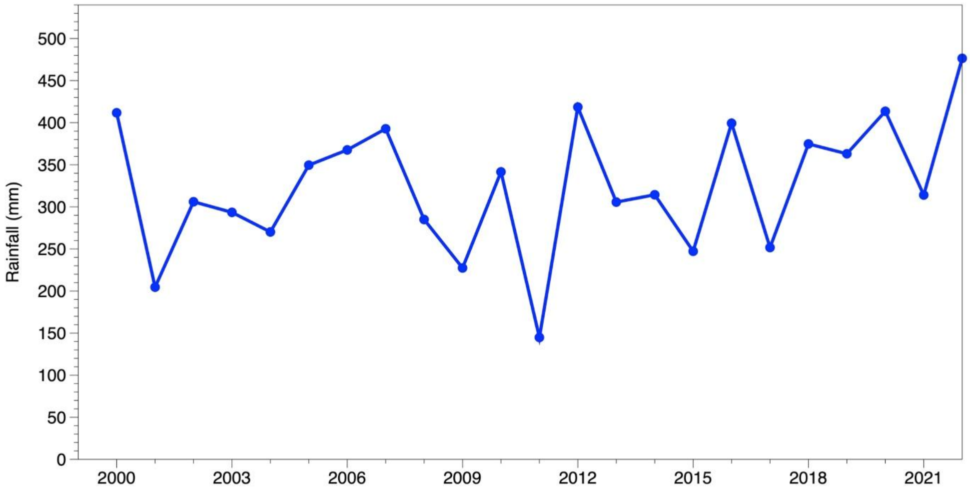

Figure 3. Annual precipitation curve for Bol from 2000-2022

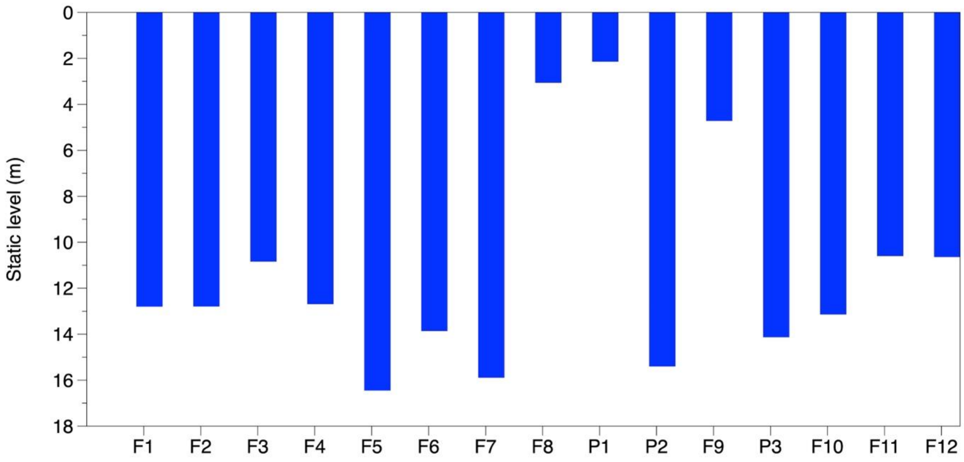

Figure 4. **Static levels at sampled water points**

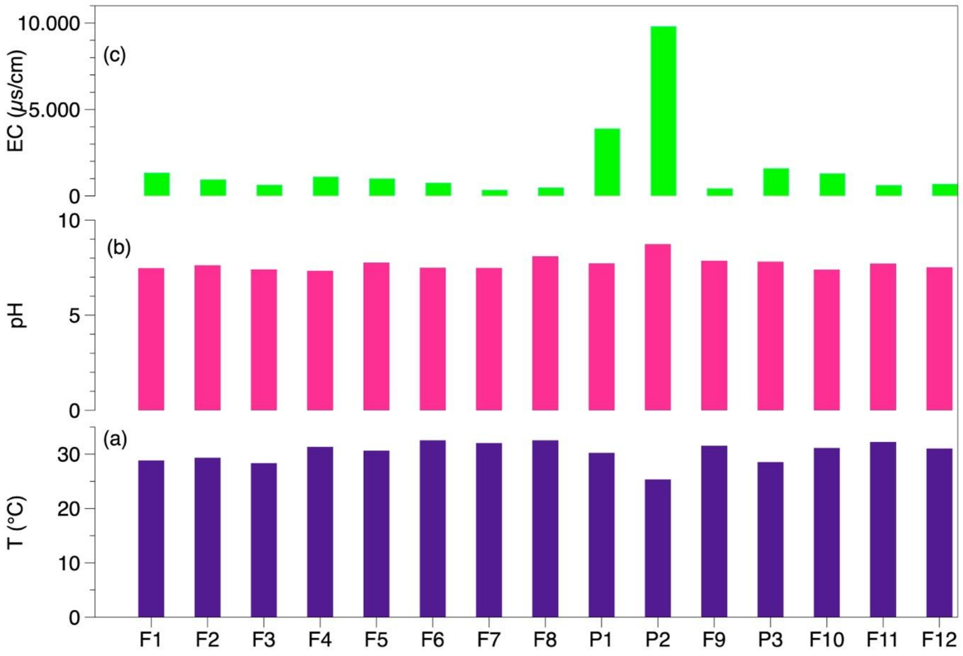

Figure 5. Variations in physico-chemicalparameters of groundwater in situ

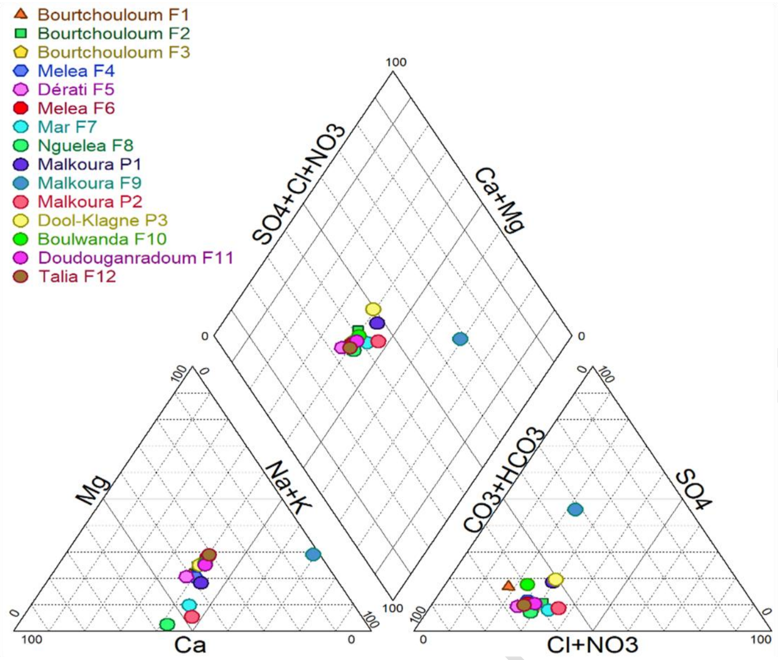

Figure 6. Water chemistry facies

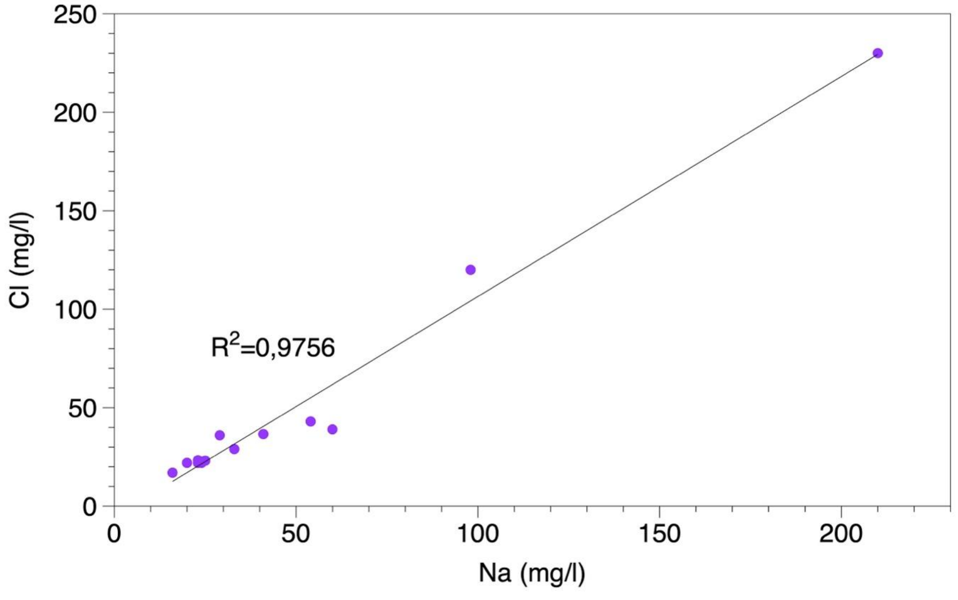

Figure 7. Correlation between chloride and sodium

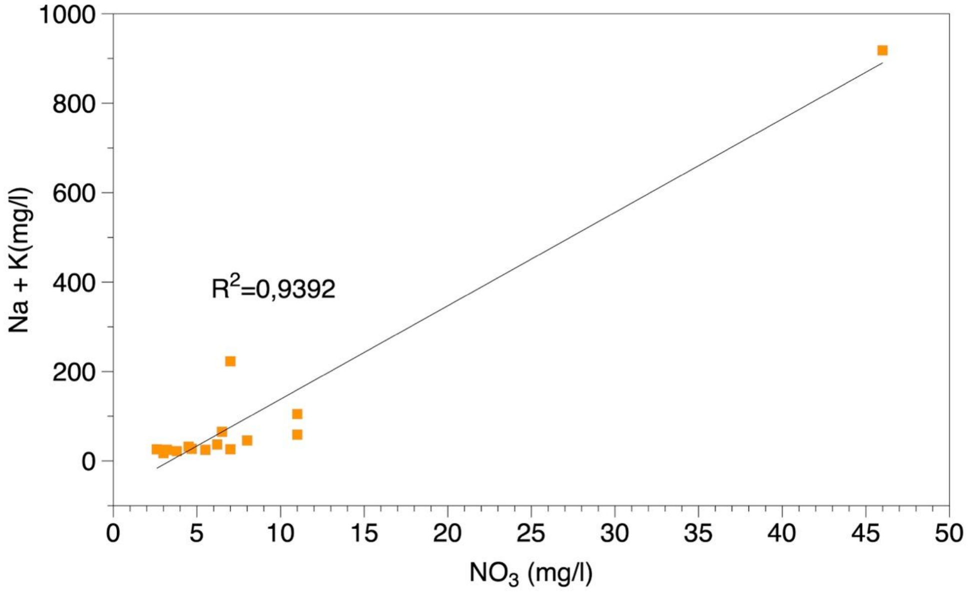

Figure 8. Correlation between sodium and potassium

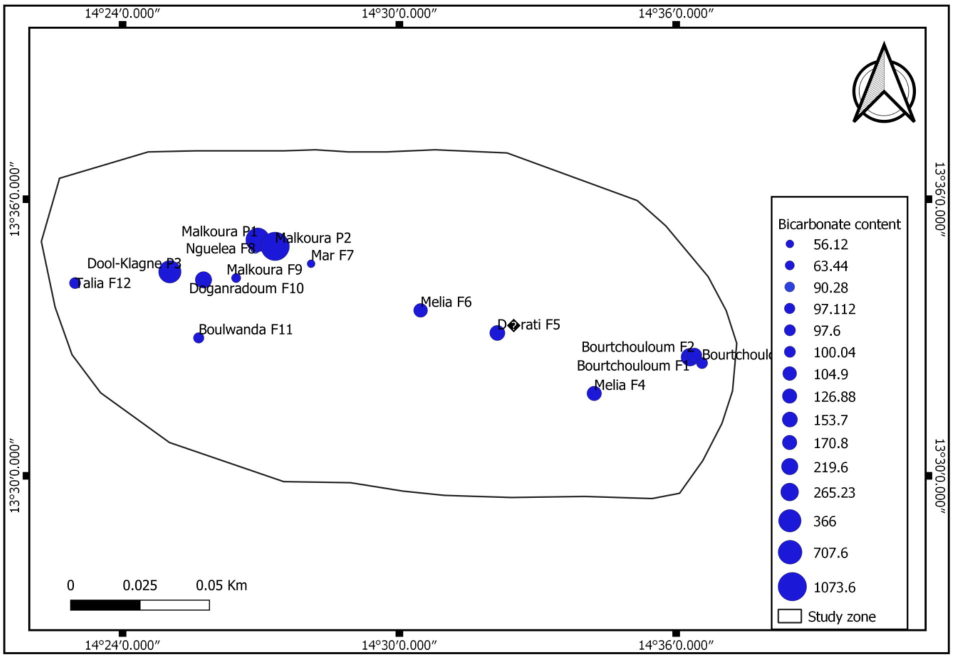

Figure 9. Spatial distribution of bicarbonate levels in the study area

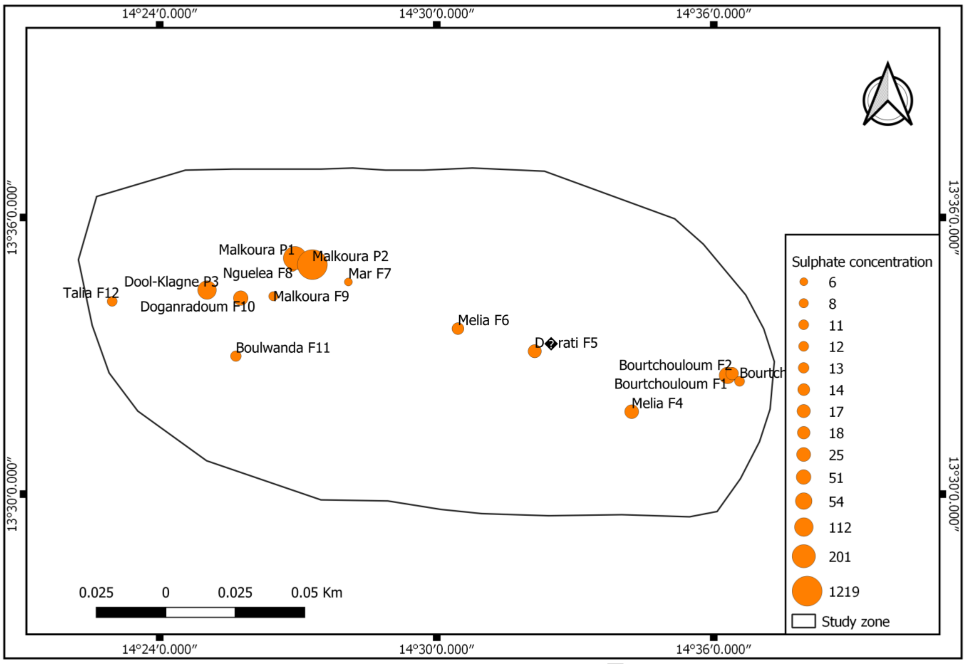

Figure 10. Spatial distribution of sulphate levels in the zone

Table 1. Correlation matrix for chemical parameters.

Variable	pH	T	CE	Cl^-	$HCO3^-$	SO4 $^{2-}$	$NO3^-$	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe^{2+}	NH4 $^+$
PH	1												
T	-0.23	1											
CE	-0.07	-0.73	1										
Cl^-	-0.14	-0.72	0.97	1									
$HCO3^-$	-0.1	-0.72	0.96	0.98	1								
$SO4^{2-}$	-0.08	-0.73	0.97	0.93	0.89	1							
$NO3^-$	-0.06	-0.74	0.94	0.88	0.85	0.97	1						
Ca^{2+}	-0.11	-0.14	0.22	0.38	0.47	0.03	-0.02	1					
Mg^{2+}	-0.07	-0.76	0.98	0.95	0.92	0.99	0.97	0.1	1				
Na^+	-0.09	-0.73	0.98	0.94	0.91	0.99	0.96	0.08	0.99	1			
K^+	-0.08	-0.72	0.97	0.98	0.99	0.91	0.87	0.43	0.93	0.92	1		
Fe^{2+}	-0.16	-0.29	0.19	0.14	0.08	0.28	0.26	-0.39	0.26	0.26	0.08	1	
$NH4^+$	0.22	-0.55	0.78	0.67	0.67	0.78	0.79	-0.07	0.77	0.78	0.72	0.14	1

Table 2. Assessment of groundwater quality in relation to physico-chemical parameters.

Sampling points	Physico-chemical pollution indicator parameters								
	CE	Cl^-	$NO3^-$	$NH4^+$	Mg^{2+}	Na^+	K^+	Fe^{2+}	$SO4^-$
Bourtchouloum F1	1332	39	6,5	1	18,322	60	5,4	0,02	54
Bourtchouloum F2	941	36	4,5	0,88	10,206	29	3	0,02	18
Bourtchouloum F3	630	23,3	5,5	0,77	8,4078	23	2,2	0,03	11
Melia F4	1101	36,6	8	1,36	11,615	41	5	0,01	25
Dérati F5	997	29	6,21	0,74	10,21	33	4	0,03	17
Melia F6	749	23,1	4,69	0,88	9,72	25	2,41	0,03	14
Mar F7	334	17	3	0,54	1,944	16	1,3	0,01	6
Nguelea F8	473	22	3,2	0,58	0,778	23	2,2	0,02	8
Malkoura P1	3890	230	7	0,88	48,6	210	13	0,01	201
Malkoura P2	9800	410	46	2	201,2	897	21	0,04	1219
Malkoura F9	427	22	3,79	0,88	1,312	20	2	0,04	8
Dool-Klagne P3	1590	120	11	0,39	34,02	98	7	0,03	112
Doudouganradoum F10	1293	43	11	1,01	18,954	54	5	0,02	51
Boulwanda F11	619	22,5	7	0,61	8,1648	24	2,4	0,02	13
Talia F12	683	22	2,6	0,74	9,6228	24	2,26	0,05	12