Original Research Article

Study of the hydrochemical characterization of drinking water from the aquifer of the town of Guitté at Hadjer Lamis

Abstract

A hydrogeological study was carried out in and around Guitté. This study aims to contribute to the understanding of the hydrochemical parameters of the waters of the Guitté aquifer. with a view to the sound and sustainable management of available water resources. A field mission to measure and sample borehole water was carried out from March 26 to 28. 2023 in and around Guitté. Physicochemical analyses were carried out on 28 water samples from human-driven pumps). The study showed that the groundwater exploited in this area has an average temperature of 29°C. Overall. the pH values measured in the sampled waters are not very heterogeneous and are around neutral. Electrical conductivity values are highly heterogeneous. Two types of chemical facies have been identified in Guitté groundwater: sodium or potassium bicarbonate facies. and calcium and magnesium bicarbonate facies. The overall quality of the groundwater obtained for consumption is 60.71% rated as good. 39.28% as poor. The origin of the mineralization could be linked. on the one hand. to water/rock contact. due to the dissolution of natron. limestone. gypsum and thenardite and on the other hand. to the phenomenon of intense evaporation.

***Keywords**: Hydrogeochemical. chemical facies. water quality. Aquifer and Guitté.*

Introduction

Groundwater and surface water resources are subject to climatic variability and the influence of human activities under various stresses on the aquifer [1]. Pressure on water resources. and on groundwater resources in particular. is increasing. mainly due to growing demand and deteriorating water quality.

In addition. problems of access to drinking water on all continents are due to the unequal distribution of available water resources on the one hand. and climate change and its adverse effects on the other [2]. According to projections. scarce freshwater resources are set to become even scarcer as a result of a number of factors. not least the ever-increasing demand for water to meet human needs [3.4]. On a national scale. Chad has between 260 and 540 billion m3 of groundwater reserves [5]. Despite this enormous groundwater potential. there is still a major challenge to be met on a national scale: access to better quality drinking water.

In fact. the study area's water needs are met by groundwater. but the latter is of dubious quality due to the fact that the majority of deep boreholes show mineralization linked to high levels of electrical conductivity. as noted in previous studies by [6] and [7]. The study area is also subject to intense evaporation. as demonstrated by [8]. confirming the predominance of evaporation. The overall objective is to contribute to the study of the hydrochemical parameters of the Guitté aquifer specifically the study plans to: (1) determine the origin of groundwater mineralization; (2) assess the physico-chemical characteristics of groundwater and (3) determine the chemical facies of groundwater.

1. Presentation of the study area

1.1. Area location

Guitté is located to the northwest of Hadjer Lamis in the Haraze Al-Biar department. more precisely in the Mani sub-prefecture. The population is estimated at 15877 inhabitants [9]. Geographically. the study area extends from 14°37'0" to 14°38'30" north latitude and 12°53'0' to 12°54'0" east longitude (Fig. 1).

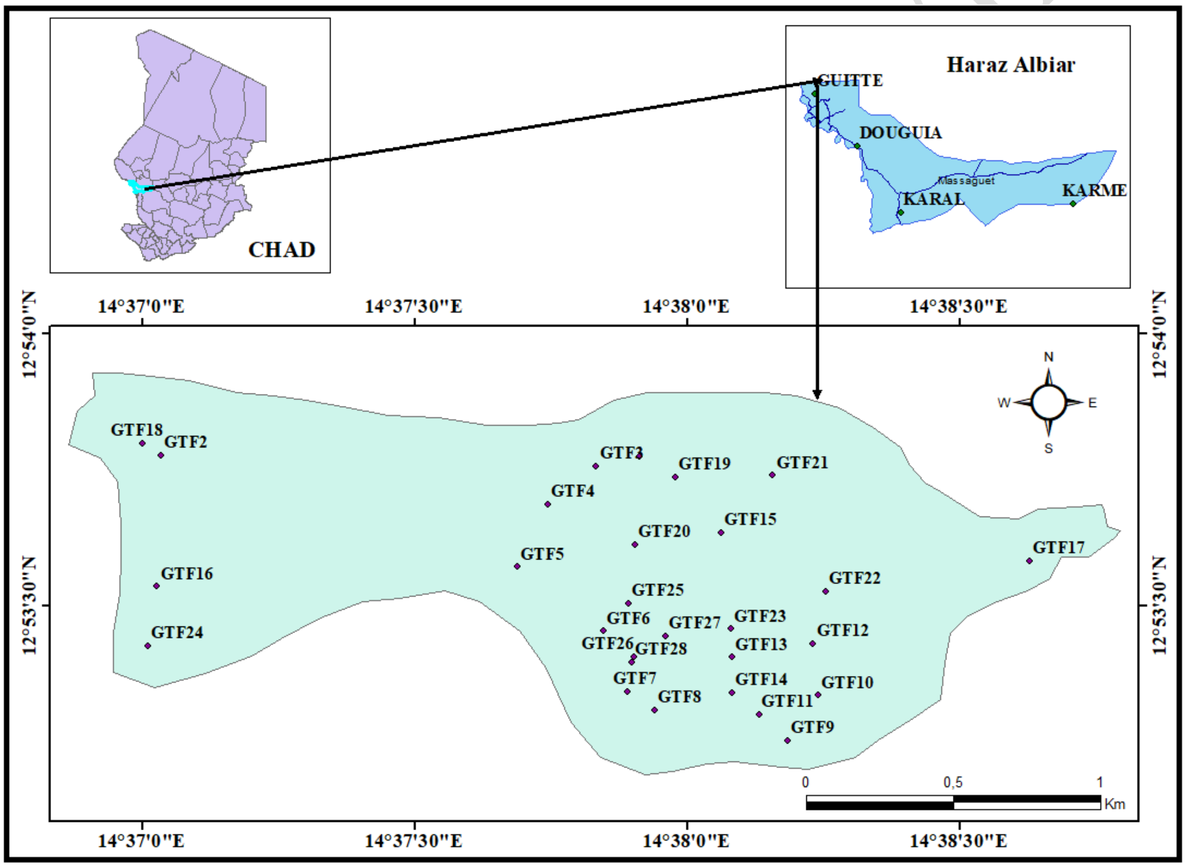

Figure 1. Location of the Guitté area. The black dots on the map represent sampling points.

1.2. Climatic and hydrological context

The study area is characterized by seasonal temperature variations. Average monthly temperatures in the area range from 32°C to 41°C. with an average of 37°C. The curve (Fig. 2) shows that the hottest periods occur in April and May. reaching up to 41°C.

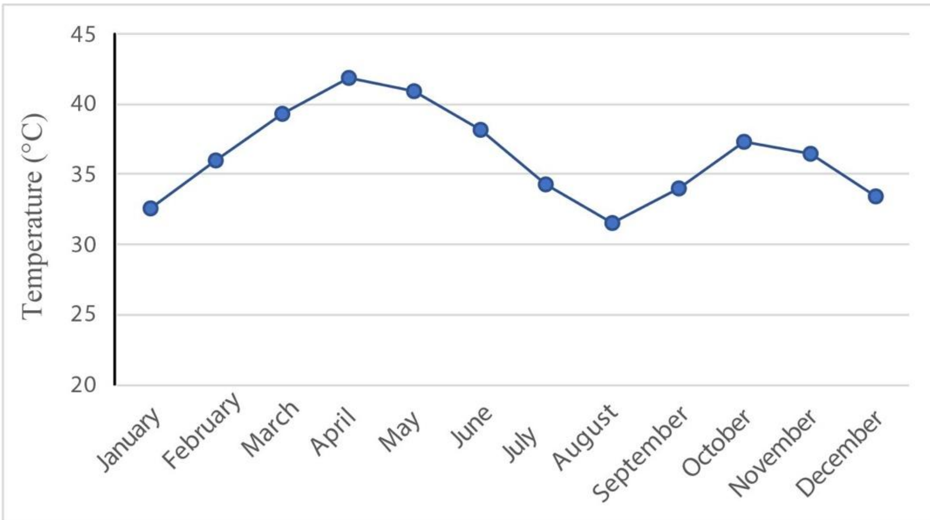

Figure 2. Average monthly interannual temperature variation from 1988 -2020 (Massakory meteorological station).

The histogram of interannual mean monthly rainfall (Fig. 3) calculated over the period 1988-2020 shows that rainfall is marked by strong temporal irregularity. The histogram shows a high rainfall rate in July and August. peaking at almost 100mm in July and 153.18mm in August.

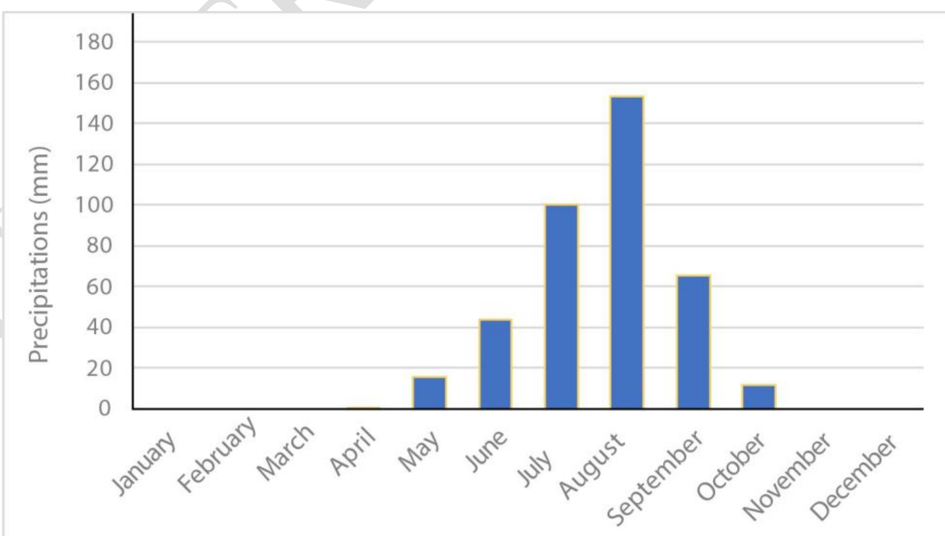

Figure 3. Monthly interannual variation in precipitation (Massakory meteorological station).

The histogram in Figure 4 shows that evaporation is very high in March and April. when it reaches maximum values due to the temperature rise. Evaporation decreases with the onset of the monsoon. reaching its minimum value in August. It rises again with the advance of the Harmattan.

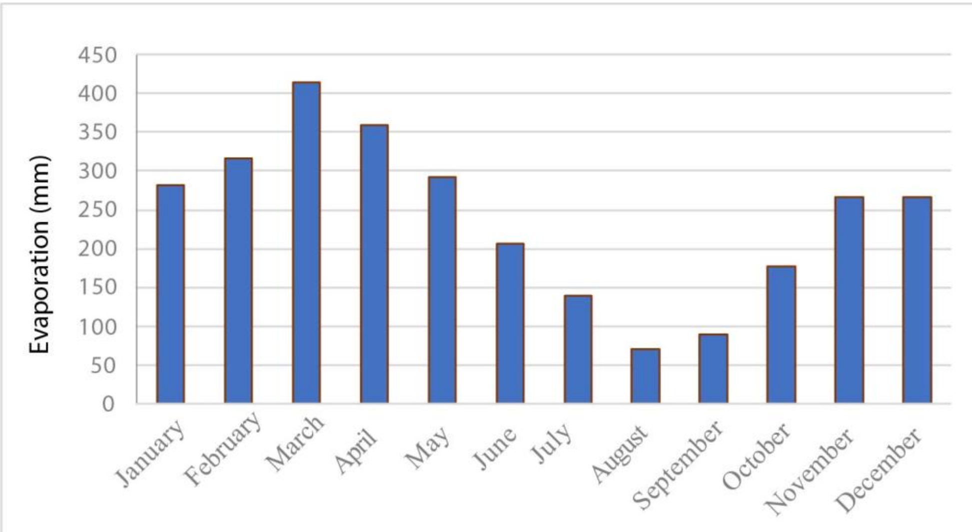

Figure 4. Variation in interannual mean monthly evaporation from 1990 to 2020 at the Massakory station.

The study area is drained by the Chari-Logone River along its western border. In the centre and east, several very gently sloping "watercourses" flow northwards. but the very flat topography makes drainage virtually impossible. During the rainy season. these rivers overflow their banks to form vast flooded areas [10].

1.3. Geology and hydrogeology

The main geological formations in the study area are derived from the Paleocene to Quaternary sedimentary cover (Fig. 5). The geological formation in the study area consists solely of fluvio-lacustrine alluvium [11]. There is a clayey lacustrine series dating from the Quaternary and a sub-actual to present-day alluvial series partially superimposed on the former [12]. The soil type in the study area is sub-arid on the sand with hydromorphic and halomorphic soils.

The subsoil in the study area is largely composed of sandy formations of variable permeability. constituting a reservoir for groundwater [13]. The shallow water table contained in the Quaternary formations is exploited for drinking water. It rests on a deep clay layer representing the bedrock of this water table. The presence of aeolian deposits favours groundwater recharge through rainwater infiltration [10].

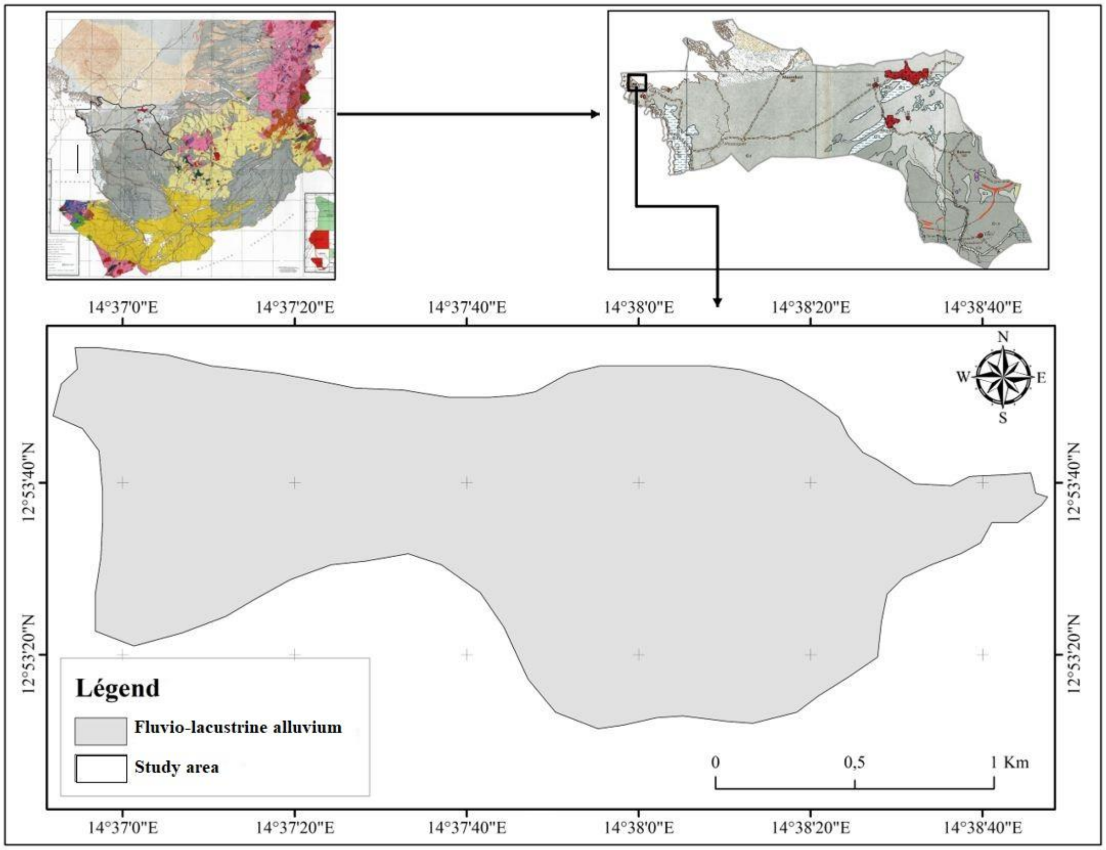

Figure 5 : *Geological map of the study area* [11]

2. Materials and methods

2.1. In-situ physico-chemical parameter measurement and sampling

The field campaign took place during the dry season from March 26 to 28. 2023 at Guitté. A total of 28 groundwater samples were taken from boreholes installed in and around Guitté.

A spatial distribution map (Fig. 1) of the sampling points was produced to represent the measurement points. Each measurement point shown on the map is a function of its accessibility in the field. and the blank area on the map explains the inaccessibility or lack of boreholes in the area.

Physico-chemical parameters were measured using a Hanna Instruments multi-parameter probe equipped with a measuring probe: pH. temperature (°C) and electrical conductivity (µS/cm).

Samples for chemical analysis (major elements) were taken in polyethene bottles (500 ml to 750 ml capacity). a material that releases very few soluble elements and therefore does not alter the chemical composition of stored samples.

2.2. Laboratory analysis

Major chemical elements are determined at the Laboratoire National des Eaux. The major elements are cations (Ca^{2+}. Mg^{2+}. Na^{+}. K^{+}). anions (Cl-. SO_4^{2-} . HCO_3^- . NO_3^-).

Ion concentrations were determined by: spectrometry using a DR3900 molecular absorption spectrophotometer (SO_4^{2-}. NO_3^-) "BWB-XP" flame photometer (K^+. Na^+). (Cl^-. HCO_3^- . Ca^{2+}) by volumetric dosage method. Mg^{2+} by calculation method. Analytical procedures are shown in Table 1.

Table 1: Type and procedure of analyses

Elements	Analysis method	Equipment used
Cl^-. HCO_3^- . Mg^{2+}. Ca^{2+}	Volumetric determination	Automatic zero burette
SO_4^{2-} . NO_3^-	Spectrometry	DR 3900 spectrophotometer
K^+. Na^+	Photometry	BWB flame photometer

Analytical method and principle of the method used for the determination of each chemical constituent of water

Determination of Ca2+ and Mg2+: The analytical method used is EDTA titrimetry. The concentration of calcium ions in a solution can be determined by titration (dosing). Initially. take 10mL of the sample and pour it into a bottle. Add one volume of CalVer2 calcium indicator solution. Stir for a while (indicator colour changes from violet-pink to blue). Proceed to spectrometry reading.

Determination of Na+. K+: The analytical method used is emission spectrophotometry. It is based on an analysis of the light spectrum characteristically emitted by excited metal atoms. The procedures used today are differentiated by the excitation method.

Determination of nitrate: NO3-: To determine nitrate. take 10 ml of sample in a bottle. add nitrate reagent. mix left and right. and proceed with the spectrophotometric reading at wavelength λ= 425 nm.

Determination of Cl-: Mohr's method of analysis is used. Chloride is determined in a neutral medium using a titrated solution of silver nitrate in the presence of potassium chromate. The end of the reaction is indicated by the appearance of the characteristic red hue of silver chromate. Its concentration in mg/l is calculated by the following formula: [Cl^-] = 354.53 * volume of silver nitrate consumed.

Determination of HCO_3^-: The analytical method used is alkalimetric titration (TA. TAC). The two values (TA. TAC) reveal the concentrations of bicarbonates. carbonates and where applicable. hydroxides (strong bases) contained in the water. In other words. the alkalinity of water corresponds to the presence of bicarbonates. carbonates and hydroxides. Its concentration is calculated using the following formula: [HCO_3^-] = 61.0168 * volume of acid consumed.

Determination of SO_4^{2-}: Sulfate reagent is added to 10 ml of sample. Shake and let stand for 5 minutes. Spectrophotometer reading at 490 nm against distilled water treated in the same way. Translated with www.DeepL.com/Translator (free version)

3. Results and discussion

3.1. Groundwater physicochemical parameters

The physicochemical parameters measured include temperature. conductivity and pH.

- ✓ **Water temperature**

Water temperature is an important factor in the aquatic environment. as it governs almost all physical. chemical and biological reactions [14]. In the study area. temperature does not vary greatly (Fig. 6) from one point to another. with a minimum of 24.4°C (GTF21) and a maximum of 30.3°C (GTF10).

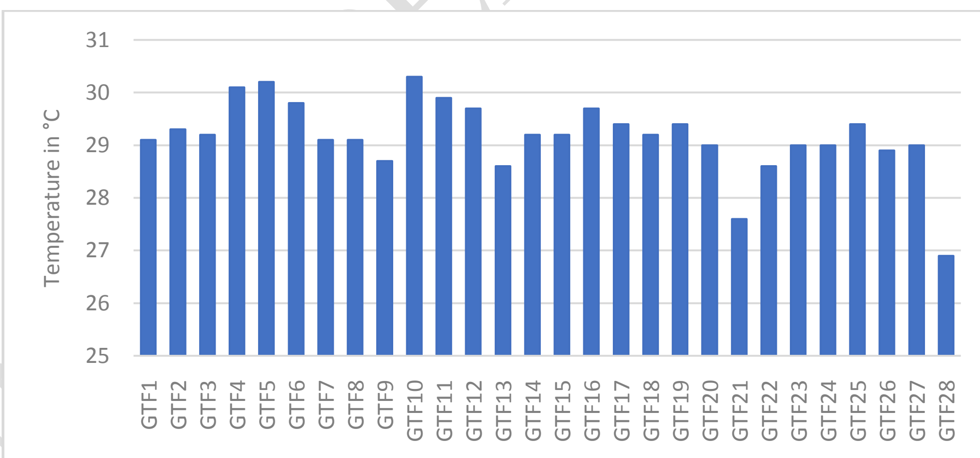

Figure 6. Variation in water temperature

- ✓ **Electrical conductivity**

Electrical conductivity refers to the ability of water to conduct an electric current. and provides information on the degree of mineralization of a water body [14]. Measured electrical conductivities vary from one structure to another. with values oscillating between 436 and 4890 µs/cm (Fig. 7). with high values observed in boreholes GTF3. GTF9. GTF10 and F25. These high values are explained by the mineralization of this borehole. with a high rate that exceeds the norm.

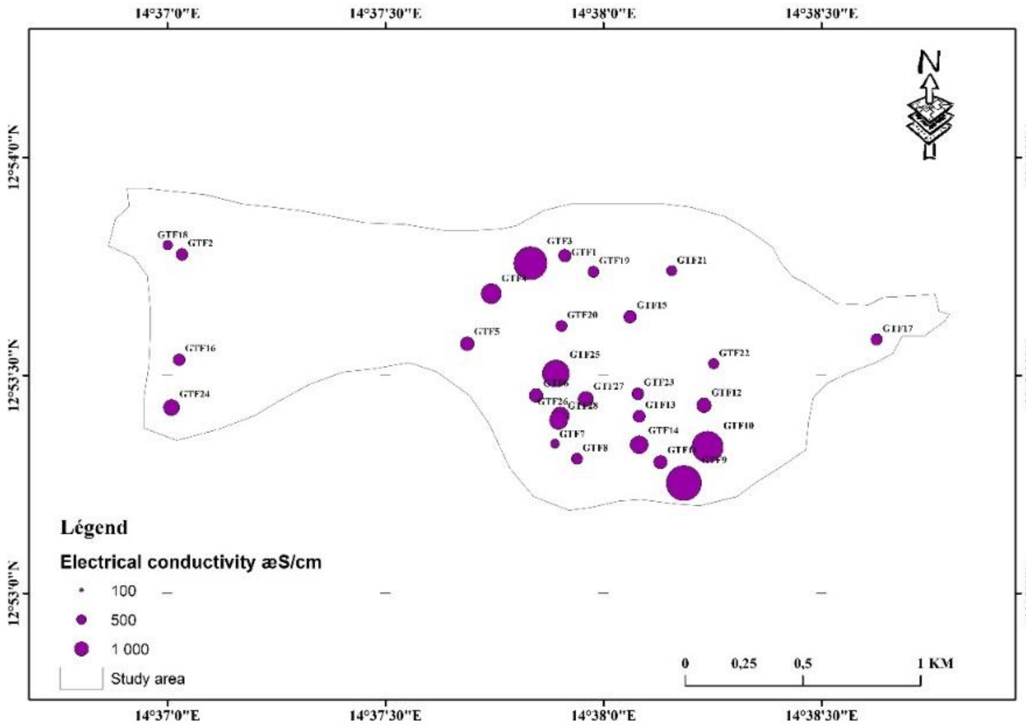

Figure 7. Spatial distribution map for electrical conductivity

- ✓ **pH**

The histogram shows that pH values in the study area do not vary greatly. with the majority of values close to neutrality (Fig. 8). According to the WHO standard. pH values range from 6.5 to 8.5. so the values in the study area meet WHO standards.

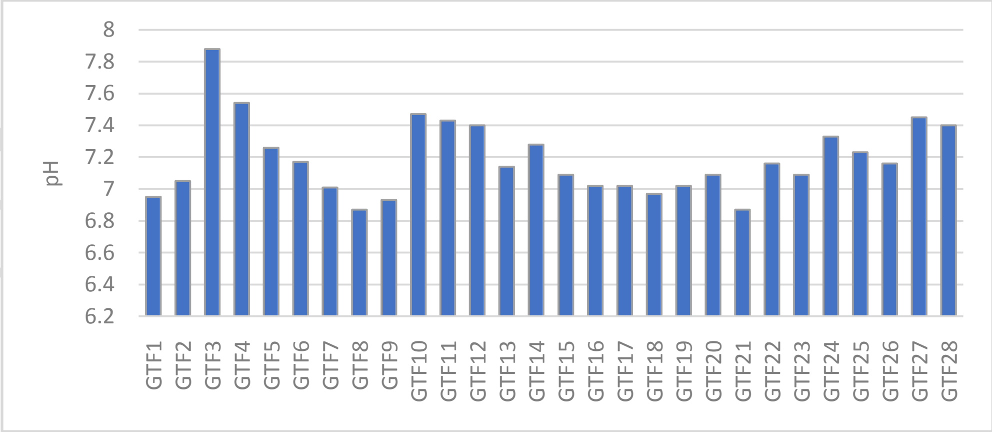

Figure 8. pH in groundwater

3.2 Analysis of chemical parameters

The results of the chemical data are shown in Table 2.

Table 2. Chemical elements in water

Sampling		**Cation in mg/L**				**Cation in mg/L**			
Code	**Locality**	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	$SO4^{2-}$	$HCO3^-$	$NO3^-$
GTF1	Guitté	56.0	4.7	34.9	12.8	43.8	43.0	170.8	6.7
GTF2	Guitté	44.0	3.3	168.0	18.0	50.0	45.0	170.8	1.7
GTF3	Guitté	410.0	17.0	296.0	43.7	390.0	468.0	976.0	5.0
GTF4	Guitté	166.0	8.0	80.0	34.0	160.0	123.0	414.8	6.9
GTF5	Guitté	80.0	5.1	216.0	14.9	73.0	68.0	238.4	4.9
GTF6	Guitté	88.0	5.0	57.7	18.4	80.0	88.0	244.0	2.2
GTF7	Guitté	23.0	2.0	18.6	8.2	23.6	12.0	97.6	5.0
GTF8	Guitté	41.0	3.5	28.6	14.2	38.8	35.0	151.3	5.0
GTF9	Guitté	510.0	19.0	288.0	58.3	420.0	484.0	1122.4	3.3
GTF10	Guitté	480.0	16.0	216.0	68.0	380.0	501.0	976.0	7.0
GTF11	Guitté	79.0	3.7	66.4	13.1	66.6	71.0	268.4	4.3
GTF12	Guitté	89.0	4.7	31.2	8.7	68.0	68.0	268.4	3.0
GTF13	Guitté	41.0	3.1	31.2	16.5	46.0	38.0	158.6	4.7
GTF14	Guitté	118.0	5.3	96.0	19.4	100.0	101.0	390.4	7.0
GTF15	Guitté	78.0	4.9	53.2	14.7	70.0	71.0	235.0	4.7
GTF16	Guitté	36.0	3.0	30.4	11.7	42.0	31.0	151.3	7.3
GTF17	Guitté	42.0	4.2	24.8	9.2	25.0	37.0	122.0	8.0
GTF18	Guitté	25.0	2.8	24.0	4.9	21.0	18.0	97.6	3.9
GTF19	Guitté	32.0	2.9	30.4	9.1	35.6	28.0	138.6	6.5
GTF20	Guitté	42.0	3.6	28.8	14.2	39.5	35.6	156.2	3.6
GTF21	Guitté	28.0	3.0	24.0	6.3	23.0	22.0	104.9	2.7
GTF22	Guitté	27.0	2.8	24.0	5.8	21.1	20.0	102.5	10.0
GTF23	Guitté	44.0	3.8	28.8	15.1	42.0	37.0	163.5	4.4
GTF24	Guitté	112.0	5.0	77.4	16.1	76.9	102.0	317.2	4.0
GTF25	Guitté	401.0	15.0	296.0	29.2	370.0	423.0	927.2	9.1
GTF26	Guitté	115.0	5.0	96.0	14.6	98.2	97.0	366.0	6.5
GTF27	Guitté	113.0	6.5	64.0	24.3	99.8	105.0	317.2	3.7

GTF28	Guitté	136.0	6.0	104.0	24.3	120.0	108.0	439.2	5.0
WHO Standards		≤200	=12	≤200	≤50	≤250	≤250	=400	≤50

✓ Order of abundance of major chemical elements

The graph in Figure 9 shows that the most dominant anions are bicarbonates (59%). sulfates (21%). followed by chlorides (19%) and nitrates (1%). while the most dominant cations are sodium (52%). calcium (38%). followed by magnesium (8%) and potassium (2%).

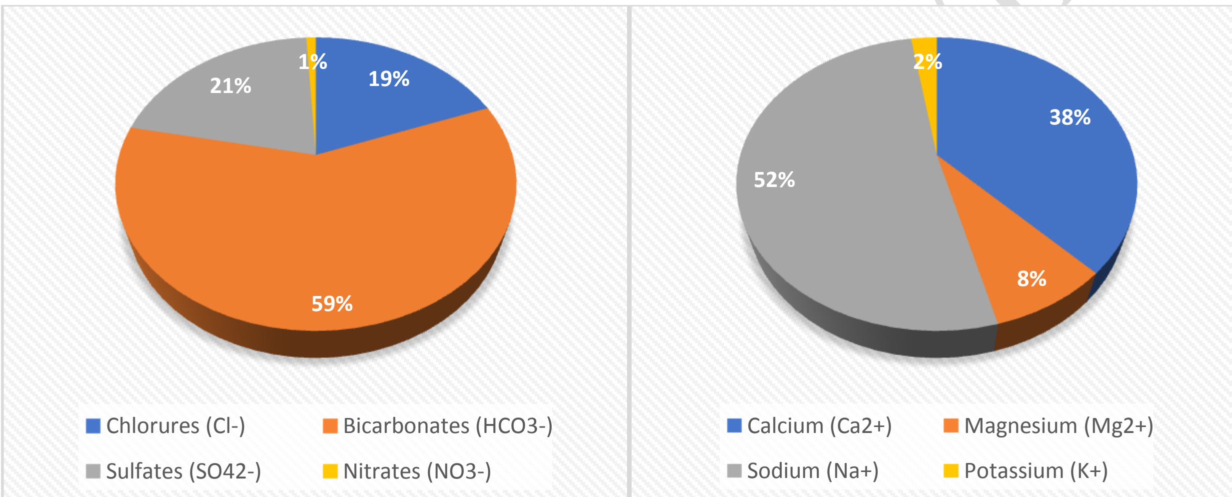

Figure 9. Proportions of anions and cations in Guitté groundwater

✓ Water chemistry

Analysis of 28 samples using the Piper diagram (Fig. 10) gives 2 chemical facies distributed as follows: (1) sodium or potassium bicarbonate facies (75%). this type of facies was reported by [6] and [7]. This bicarbonate-sodium predominance can be justified by the high bicarbonate and sodium contents recorded in the waters; (2) bicarbonate-calcium and magnesium facies (25%). this type of facies was noted by [15] where 58% of the waters analyzed in the Chari Baguirmi are bicarbonate-calcium.

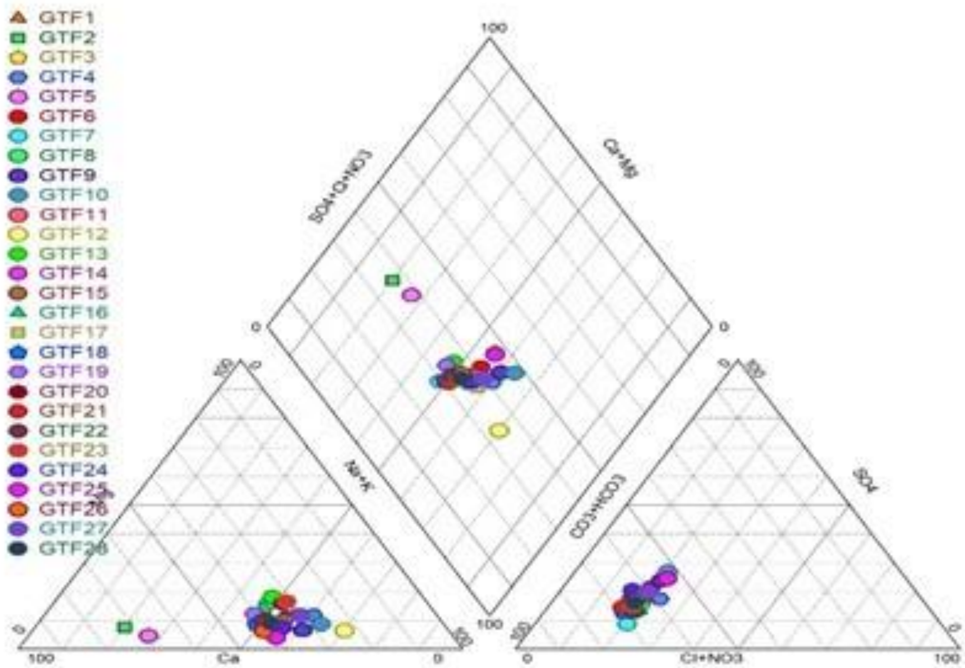

Figure 10. Groundwater hydrochemical facies at Guitté

- ✓ **Origin and processes of water mineralization**
  - **Bicarbonate (HCO_3^-)**

The bicarbonate ion content is the highest (representing 41% of mineralization). occupying the most dominant proportion in groundwater. as noted by [7] in his studies in the department of Haraze Albiar. The amount of bicarbonate ions varies from point to point. ranging from 32.5 mg/L to 1122.4 mg/L. with an average of 321.3 mg/L. A high bicarbonate content in groundwater depends above all on the presence of carbonate minerals in the soil and aquifer. as well as the CO_2 content of the air and soil in the catchment area [16]. According to WHO guidelines. the bicarbonate content in water must be ≤400mg/L. but 21.42% of the water analyzed did not meet this standard. compared with 78.57% that did.

  - **Chloride (Cl^-)**

Chloride levels range from 21 mg/L to 420 mg/L (Fig. 11). with an average of 107.99 mg/L. Chloride levels increase from north to south (This high chloride concentration closely follows the evolution of total water mineralization. This high presence in the water at points (F3. F9. F10 and F25) could be due to the use of the chloride-rich amendment used in the Lake Chad polders [15]. In addition to their conservative characteristics. chloride ions tend to concentrate in waters subject to evaporation [17]. of which the study area is no exception.

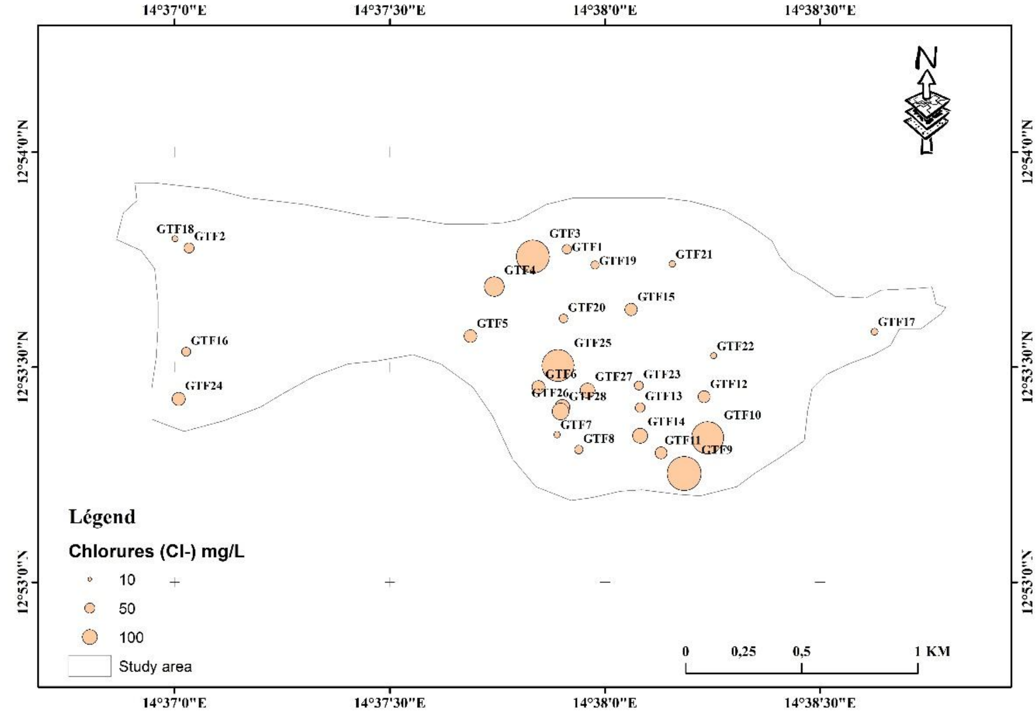

Figure 11. Spatial distribution map of chlorides in Guitté waters

- **Sodium (Na^+)**

Analysis of the data (Fig. 12) showed that sodium levels accounted for 15% of overall mineralization. second only to bicarbonate. Levels ranged from 12 mg/L to 510mg/L. with an average of 119.5mg/L. In addition. excess sodium may result from the dissolution of sodic sulphate minerals [18.19]. such as thenardite (Na_2SO_4) found in formations on the southeastern edge of Lake Chad [20. 21]. The WHO standard requires the sodium value in water to be ≤ 200mg/L. Points GTF3. GTF9. GTF10 and GTF25 (Fig. 12) exceed the WHO standard with a very low proportion of 14.28%. but 85.71% meet the WHO standard.

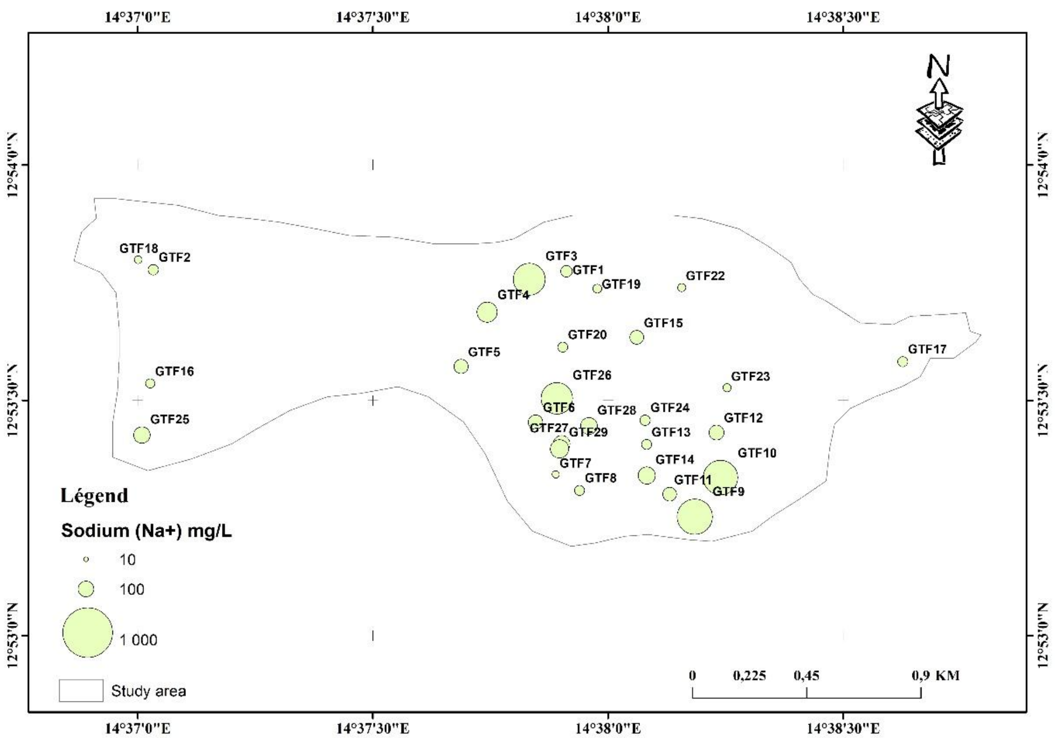

Figure 12. Spatial distribution map of groundwater in sodium

- ✓ **The correlation between abundant chemical elements**
  - **Relationship between electrical conductivity and bicarbonate**

Since electrical conductivity has the power to assess water mineralization. it is essential to relate it to bicarbonate. the most abundant element in water. in order to determine the degree of correlation. Figure 13A shows that bicarbonate ions (HCO_3^-) make a major contribution to mineralization in the waters studied. This is confirmed by the high levels of bicarbonate ions compared with other major elements. and their very good correlation (R^2 = 0.97) with electrical conductivity.

- **Bicarbonate/sodium relationship**

The plot of HCO_3^- versus Na+ (Fig. 13B) shows that these chemical elements correlate very well. with R^2=0.98. Bicarbonate ions are in the majority of the water. The presence of these two chemical elements in the water could be attributed to the dissolution of natron ($NaHCO_3$).

- **Calcium and sulphate relationship**

The graph (Fig. 13C) shows two groups of points. a first group where the points align around the equilibrium line R^2=0.98. which could be influenced by the dissolution of gypsum and/or anhydrite (the solubilization of gypsum releases Ca^{2+} and SO_4^{2-} ions according to the equation: $CaSO_4.2H_2O \rightarrow Ca^{2+}$.

SO_4^{2-} + $2H_2O$). a second group formed by more mineralized water points showing an excess of calcium Ca^{2+}.

- **Sodium and sulfate relationship**

The graph (Fig. 13D) shows that Na+ and SO_4^{2-} ions have a very good correlation R^2= 0.98. and also highlights the majority contribution of sodium ions compared to sulfate. This excess of sodium ions could result from the dissolution of sodium sulfate minerals [18.19]. such as thenardite (Na_2SO_4).

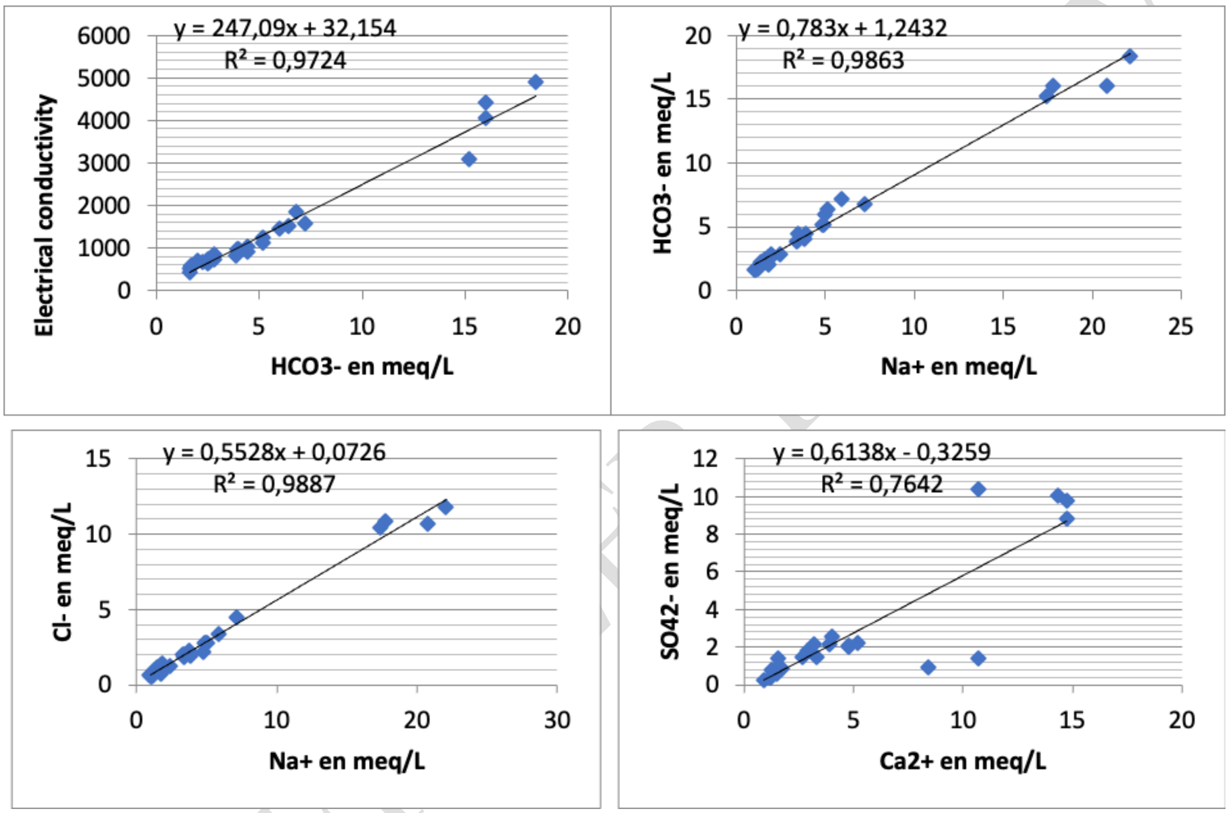

Figure 13. Relationship between chemical elements

3.3. Overall groundwater quality

Groundwater quality is assessed by studying pollution parameters. then interpreting overall quality on the basis of physico-chemical standards (WHO standards). The three indicator parameters for physicochemical and nitrogen pollution are :

- Electrical conductivity. which provides information on the mineralogical quality of the water;
- Chloride ions. which provides information on mineralogical water quality;
- Nitrates. the main indicators of groundwater pollution [14].

Table 3 shows the global water assessment grid.

Table 3: Grid for assessing water quality for consumption (WHO)

Classes	Cl^- (mg/L)	NO_3^- (mg/L)	Electrical conductivity (µs/cm)
Good	≤250	≤50	≤1000
Poor	>250	>50	>1000

The water in samples GTF1. GTF2. GTF5. GTF6. GTF7. GTF8. GTF11. GTF13. GTF15. GTF16. GTF17. GTF18. GTF19. GTF20. GTF21. GTF22 and GTF23 is generally of good quality. with 60.71% of water analyzed. This quality is due to :

- Mineralization. with maximum recorded values of 963 µS/cm (good quality);
- Chloride levels (good quality);
- Nitrates. which vary from a minimum of 1.7 mg/L to a maximum of 13 mg/L (good quality).

With the exception of water points GTF3. GTF4. GTF9. GTF10. GTF12. GTF14. GTF24. GTF25. GTF26. GTF27 and GTF28. 39.28% of the water analyzed was of poor quality. This poor water quality is linked to mineralization due to high electrical conductivity values.

Conclusion

This study assessed the physico-chemical quality of the water in and around the Guitté aquifer. This study shows that the groundwater exploited in this area has an average temperature of 29°C. The pH ranges from 6.87 to 7.88. with an average of 7.19. Electrical conductivity values are highly heterogeneous. ranging from 436 to 4890 µs/cm. with an average of 1351.78 µs/cm. Analysis of the chemical results shows that water from boreholes GTF3. GTF9. GTF10 and GTF25 are highly mineralized. Overall water quality revealed that 60.71% of the points monitored were of good quality. compared with 39.28% of poor quality. These waters belong to two types of facies: sodium and potassium bicarbonate facies. and calcium and magnesium bicarbonate facies. The origin of the mineralization is essentially due to agricultural amendment. and the dissolution of natron. gypsum and thenardite.

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