Assessment of Physico - Chemical Quality of Surface Waters in Lake Lere Basin, Chad

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Abstract: ***The Lake Lere basin is subject to human pressure, which results in the degradation of water quality. . In order to establish a diagnosis of surface water quality, the aim of this study was to assess the physico - chemical parameters of surface water in the Lake Lere basin. Water samples were analyzed using various analytical methods to assess these parameters. Physical parameters were measured in situ using the electrochemical method with an electrical multiparameter. Chemical parameters were analysed using the spectro - colorimetric method with electronic spectrophotometers. Results indicate that the water in Lake Lere has an average temperature of 30.1°C, a neutral pH of 6.9, and low mineral content with an average conductivity of 166.03 µS/cm. The average concentrations of various mineral ions were, for the most part, in line with international standards. Thus, we noted in mg/L, respectively: sodium Na^+ (8.08), potassium K^+ (1.92), calcium Ca2$^+$ (70.95), magnesium Mg^{2+} (57.93), chloride Cl^- (0.85), nitrate NO_3^- (19.35), sulphate SO_4^{2-} (21), phosphate PO_4^{3-} (4.58) and silica SiO_2 (52.13). The results of the principal component analysis showed that the different groups of sites were characterised by a contribution of nutrients mainly from agricultural activities and chemical alteration of the soils. The Lake Lere basin faces significant human pressure, leading to water quality degradation. This study assesses the physico - chemical parameters of surface water in the basin. Water samples were analyzed using electrochemical and spectro - colorimetric methods. Results indicate an average water temperature of 30.1°C, a neutral pH of 6.9, and low mineral content with an average conductivity of 166.03 µS/cm. The principal component analysis revealed that agricultural activities and soil chemical alterations influence water quality. The study also identified two primary chemical facies: bicarbonate - calcium - magnesium and sulfate - calcium - magnesium. The Riverside diagram analysis suggests that the water is suitable for agricultural use.***

Keywords: Physico - chemistry, Hydrochemistry, Surface water, Water quality, Lake Lere, Chad

1. Introduction

Surface water is essential to all human activity, especially agriculture and industry. Among continental hydrosystems, lakes are particularly notable for their capacity to support biological resources. (H. Alayat and C. La mouroux, 2007). They play a significant role in climate regulation and economic growth in many countries. According to (N. Koné, 2022), much of the drinking water currently consumed in the world comes from surface waters, mainly lakes. However, discharges of domestic and industrial wastewater into the environment, excluding run - off, are estimated at around 359 billion m^3 (Planétoscope, 2012). This wastewater is drained into the environment without any treatment. Wastewater, whatever its origin and nature, contains dissolved or particulate organic and inorganic micropollutants that irreversibly affect the quality of natural waters (C. E. Delisle and J. W. Schmidt, 1977); (S. C. Louise, 2008); (R. Sébastien, 2014); (B. Batoul, 2018).

In Chad, groundwater and surface water resources amount to between 263 and 455 billion m^3 per year from rivers and run - off. However, because of the population explosion, urban waste management is becoming a problem (S. A. M. Mahamat and al., 2015). Wastewater is drained directly into rivers or lakes (N. Ngaram and al., 2011). Industries and urban areas are usually located close to rivers and lakes. This inevitably affects their physico - chemical quality. The Lake Lere basin is one of the potential areas for agricultural activity and mineral exploitation. To increase agricultural yields, farmers use fertilisers and pesticides, which have a visible impact on water quality (T. Souareba and al., 2024). Research in the fields of geology (O. Baldal and al., 2013) and geography (P. Kedeu, 2021) has shown that the nature, properties and dynamics of the soils and rocks in the Léré area are likely to cause them to deteriorate, leading to an accumulation of minerals (D. Nadjiam, 2013). Due to the impact of human activities and soil alteration on water quality, assessing the physico - chemical parameters of Lake Lere was essential.

2. Materials And Methods

2.1 Material

Presentation of the study area: The Lake Lere basin is located in the extreme south - west of Chad. The lake currently covers an area of approximately 40 km2 during low - water periods and 50 km2 during high - water periods, with an average depth varying between 4 and 8 m (P. Kedeu, 2021). The basin is centred on 9.37° North longitude and 14.10° East latitude. It receives tributaries from three main catchments: the Mayo - Kebbi, the Mayo - Binder and the El - Ouaya. The Mayo - Kebbi rises from the hydrographic network formed at the end of the gullied valleys of the marigots separated by the sandbanks (P. Kedeu, 2021). It drains into Lake Lere, crossing Lake Trene to the east (Figure 1). The Mayo - Binder and El - Ouaya belong to the temporary regime. The Mayo - Kebbi, on the other hand, is semi - permanent. The Lake Lere basin, like the extreme south - west of Chad, is dominated by a Sudanian - type climate, marked by the alternation of two main seasons: a dry season from November to April and a wet season from May to October. Average rainfall in the Lake Lere department is around 854 mm per year. This rainfall pattern is characterised by chronic irregularity in time and space (P. Kedeu, 2021). Wind speed is around 10 m/s. The average air temperature hovers around 45°C during heatwaves (NASA, 2024). However, wind and temperature are determining factors in the soil erosion mechanism (L. Gouaidia, 2008).

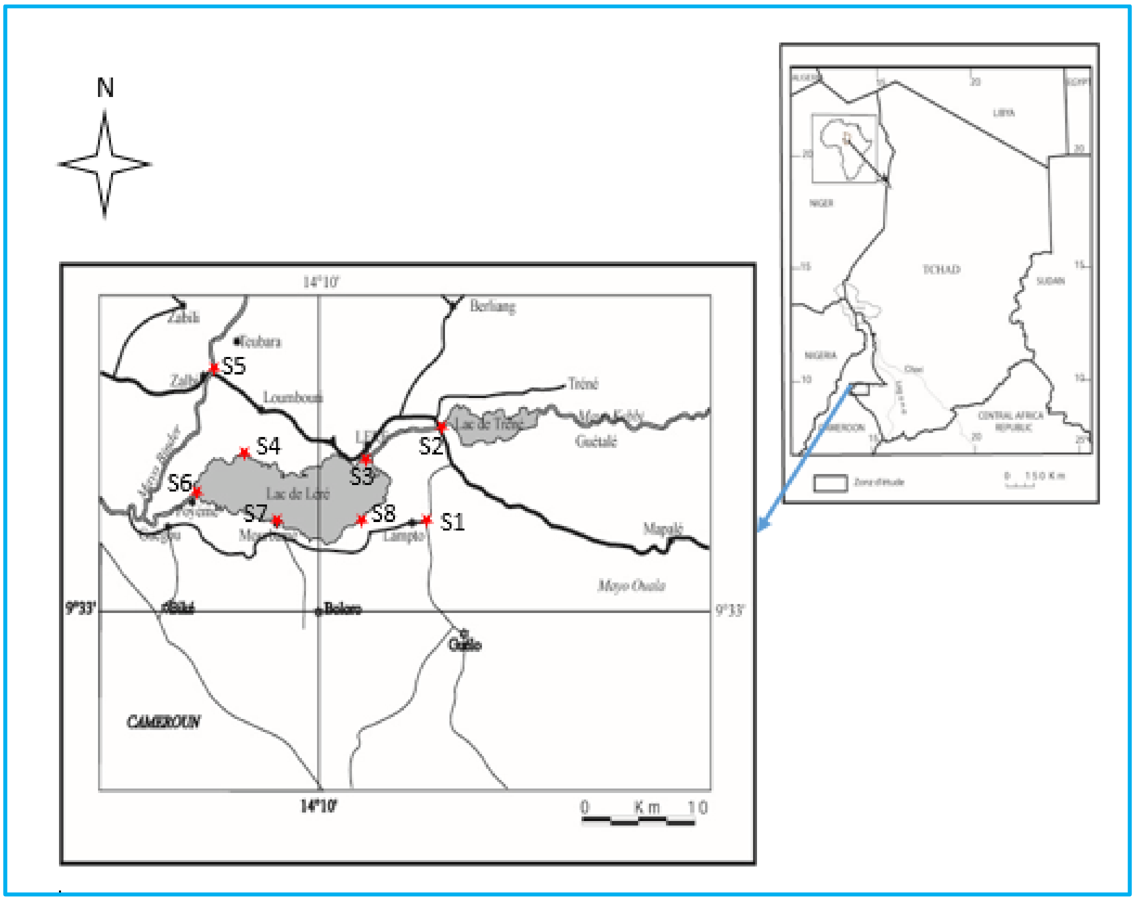

Figure 1: Map showing the location of the study area and sampling points

Sampling: The samples were taken in September 2023, a period of high water levels. This period coincides with the period when fertilisers are spread and fields are treated with pesticides. Based on the activities carried out, 8 sites were chosen and 1.5 litres of water was taken from each of these eight points. Samples were taken from a depth of more than 20 cm. Before sampling, the bottles (made of ethylenic plastic) were rinsed with demineralised water and then rinsed three times with water from the sampling site. Immediately after sampling, the samples were labelled and stored in a fridge at around 4°C before being transported to the Hydrogeosciences and Reservoirs Research Laboratory for analysis (J. Rodier, and al., 2009).

2.2 Methods

Sample analysis: The various methods for measuring and analysing samples taken from the book by Rodier (J. Rodier, and al., 2009) and the Association Française de Normalisation (AFNOR) are listed in Table 1.

Table 1: Summary of equipment and methods for analysing physico - chemical parameters in water.

Parameters studied	Apparatus and methods
T°, pH and conductivity	In - situ measurement using a HANNA HI 8915 multimeter
Sodium and potassium	Spectrometric method using the JEANZAY - PFP7 flame spectrophotometer
Calcium, magnesium bicarbonate and chloride	Titrimetric method using the HACH - SI Analytics automatic titrator
Nitrate, sulphate, phosphate and silica	Spectrometric method using the HACH - LANGE Link2SC DR 3900 spectrophotometer.

***Data analysis and processing**:* Principal component analysis and analysis of variance (ANOVA) were performed using IBM SPSS statistics 25 software. The hydrochemical diagrams were constructed using the DIAGRAM programme.

3. Results and Discussion

3.1 Results

The results presented in Table 2 show that most of the physico - chemical parameters such as temperature, pH, electrical conductivity and mineral ions analysed in the surface waters of the Lake Lere basin vary according to the sampling stations. The physico - chemical variables correlate with each other and are influenced by each other. The different chemical facies of the water are illustrated by the construction of different water digrams.

Variation in physical parameters: Temperature varies from 28 (S5 and S6) to 32°C (S8) with an average of 30.1°C. This variation in temperature is not statistically significant at the 95% level. The pH varied from 6.3 (S3) to 7.4 (S1) with an average of 6.9. The average pH value of the Léré water is close to 7. The analysis of variance shows a non - significant variation in pH at the 95% level. The pH varies from 6.3 (S3) to 7.4 (S1) with an average of 6.9. The average pH of the Léré water is close to 7. The average pH value of the Léré water is close to 7. The analysis of variance shows a non - significant variation in pH at a level of 95%. The highest value for electrical conductivity (492 µS/cm) was obtained at station S1 and the lowest at station S8 (98 µS/cm). The average conductivity of the surface waters of Lake Léré obtained during this period was 166.03 µS/cm. The analysis of variance shows a statistically significant difference in electrical conductivity between points at a confidence level of 95%.

Variation in mineral ion concentrations: The sodium concentration varied from 7.5 (S6) to 9.3 mg/L (S8) with an average of 8.08 mg/L. Analysis of variance shows a non - significant difference in Na^+ concentration. Potassium concentration varied from 1.5 (S6) to 2.4 mg/L (S8) with an average of 1.92 mg/L. Analysis of variance shows a non - significant difference in K+ concentration. Magnesium concentration varied from 27 (S6) to 106.3 mg/L (S7) with an average of 57.93 mg/L. The analysis of variance shows a statistically significant difference in Mg^{2+} concentration at the 95% level between the sampling points. Calcium concentration ranged from 34.4 (S8) to 120.4 mg/L (S3) with an average of 70.95 mg/L. The analysis of variance shows a significant difference in Ca^{2+} concentration at the 95% level. The silica concentration varies from 31 (S3) to 88.7 mg/L (S5) with an average of 52.13 mg/L. The analysis of variance shows a significant difference in SiO_2 concentration at a level of 95%. The chloride concentration varies from 0.4 (S3 and S8) to 1.6 mg/L (S1) with an average of 0.85 mg/L. Analysis of variance shows a non - significant difference in Cl^- concentration at the 95% confidence level. The nitrate concentration in the water ranged from 4.3 (S3) to 57.8 mg/L with an average of 19.35 mg/L. Analysis of variance shows a non - significant difference in Cl^- concentration at the 95% confidence level. The nitrate concentration in the water ranged from 4.3 (S3) to 57.8 mg/L with an average of 19.35 mg/L. The analysis of variance shows a significant difference in variation in NO_3^- concentration at a 95% confidence level. The sulphate concentration in the water ranged from 8 (S3) to 52 mg/L (S5) with an average of 21 mg/L. Analysis of variance shows a significant difference in SO_4^{2-} concentration at a 95% confidence level. The bicarbonate concentration in the water ranged from 9.4 (S5) to 23.73 mg/L (S1) with a mean of 14.48 mg/L. Analysis of variance indicates a significant difference in HCO_3^- concentration at a level of 95%. Finally, the phosphate concentration varies from 0.89 (S8) to 7.88 mg/L with an average of 4.58 mg/L. The analysis of variance indicates a significant difference in the concentration of PO_4^{3-} at a level of 95%.

Table 2: Distribution of values of physico - chemical parameters analysed in the surface waters of the Lake Léré basin according to sites.

Paramètres	Unité	S1	S2	S3	S4	S5	S6	S7	S8	M
T	°C	31	31	31	30, 2	28	28	30	32	30, 1
pH	-	7, 4	6, 5	6, 3	6, 9	6, 9	7, 3	7, 2	7, 1	6, 9
CE	µS/cm	492	113, 5	92, 9	92, 7	208	119	114	98	166, 03
Na^+	mg/L	8, 3	7, 6	8	8, 1	7, 9	7, 5	8	9, 3	8, 08
K^+	mg/L	2, 1	1, 7	1, 9	2	1, 8	1, 5	2	2, 4	1, 92
Mg^{2+}	mg/L	78, 6	33, 7	30, 1	54, 7	50, 9	27	106, 3	82, 2	57, 93
Ca^{2+}	mg/L	68, 8	86	120, 4	51, 6	86	68, 8	51, 6	34, 4	70, 95
SiO_2	mg/L	46, 2	43, 1	31	47, 2	88, 7	51	46, 5	63, 4	52, 13
Cl^-	mg/L	1, 6	1, 4	0, 4	0, 5	0, 7	1	0, 8	0, 4	0, 85
NO_3^-	mg/L	8, 6	14, 3	4, 3	12, 9	57, 8	16, 9	14, 2	25, 8	19, 35
SO_4^{2-}	mg/L	12	18	8	17	52	17	18	16	21
HCO_3^-	mg/L	23, 73	16, 88	10, 4	9, 5	9, 4	12, 26	13, 9	11, 84	14, 48
PO_4^{3-}	mg/L	5, 32	1, 08	7, 88	5, 41	2, 69	5, 98	7, 43	0, 89	4, 58

S1 - 8: Site 1 - 8; M: Average

Principal component analysis: Table 3 shows that temperature correlates negatively with conductivity and bicarbonate. pH correlates positively with silica and magnesium and negatively with calcium. Electrical conductivity correlates positively with bicarbonate and chloride. Nitrate correlates positively with sulphate and silica and negatively with phosphate. Sulphate correlates positively with silica and negatively with phosphate. Bicarbonate correlates positively with phosphate. Phosphate correlates negatively with silica. Sodium correlates

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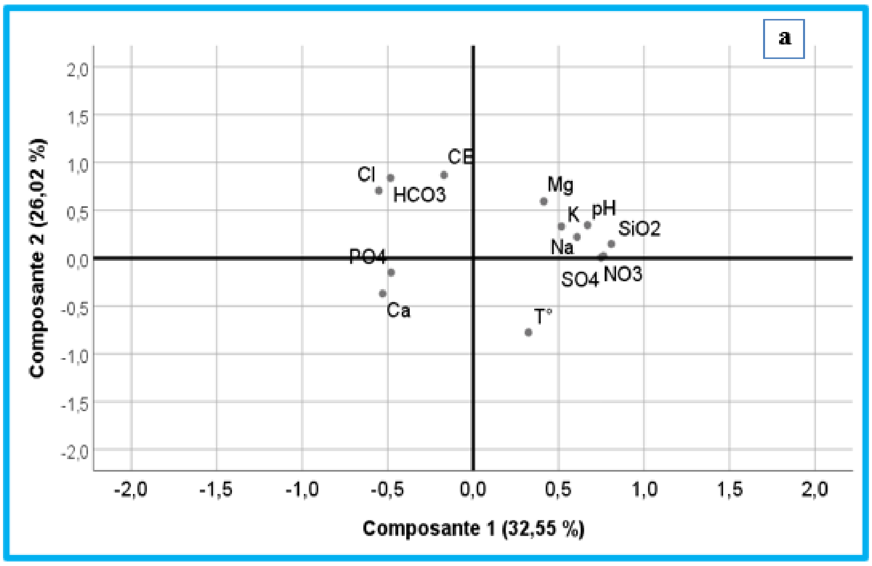
positively with potassium and magnesium and negatively with calcium. Potassium correlates negatively with calcium and magnesium. Finally, calcium correlates negatively with magnesium. Figures 2a and 2b show the distribution of variables between the two main axes. Component 1 explains 32.55% of the total variance. The positive part of this component includes nitrate, silica, sulphate, sodium, potassium, magnesium and pH, and the negative part phosphate and calcium. Component 2 provided 26.02% of the information.

The positive part of this category includes electrical conductivity, bicarbonate and chloride, and the negative part temperature. According to Figure 2b, sulphate, nitrate, sodium, potassium and magnesium come mainly from sites S4, S5 and S8 and are influenced by pH variation. Phosphate and calcium come from sites S2, S3 and S6. Finally, chloride and bicarbonate come from station S7 and are influenced by temperature, which causes the significant variation in electrical conductivity.

Table 3: Correlation matrix between the physico - chemical parameters analysed in the surface waters of the Lake Lere basin.

	T°	pH	CE	NO_3	SO_4	HCO_3	PO_4	Cl	SiO_2	Na	K	Ca	Mg
T°	**1, 00**												
pH	- 0, 13	**1, 00**											
CE	**- 0, 77**	0, 26	**1, 00**										
NO3	- 0, 08	0, 45	- 0, 01	**1, 00**									
SO4	- 0, 08	0, 48	- 0, 01	**0, 99**	**1, 00**								
HCO3	**- 0, 73**	- 0, 16	**0, 79**	- 0, 39	- 0, 38	**1, 00**							
PO4	- 0, 07	0, 02	0, 03	**- 0, 50**	**- 0, 51**	- 0, 04	**1, 00**						
Cl	**- 0, 86**	- 0, 23	**0, 67**	- 0, 19	- 0, 19	**0, 88**	- 0, 13	**1, 00**					
SiO2	- 0, 12	**0, 55**	0, 09	**0, 97**	**0, 96**	- 0, 30	**- 0, 53**	- 0, 15	**1, 00**				
Na	0, 41	0, 31	0, 07	0, 06	0, 06	0, 01	- 0, 34	- 0, 38	0, 19	**1, 00**			
K	0, 30	0, 40	0, 16	- 0, 06	- 0, 03	0, 11	- 0, 19	- 0, 31	0, 06	**0, 94**	**1, 00**		
Ca	- 0, 06	**- 0, 50**	0, 02	- 0, 07	- 0, 09	- 0, 05	0, 27	0, 07	- 0, 25	**- 0, 54**	**- 0, 51**	**1, 00**	
Mg	- 0, 18	**0, 54**	0, 26	0, 01	0, 05	0, 28	0, 04	- 0, 01	0, 13	**0, 57**	**0, 71**	**- 0, 67**	**1, 00**

Values in **bold** are statistically significant at the 95% confidence level.



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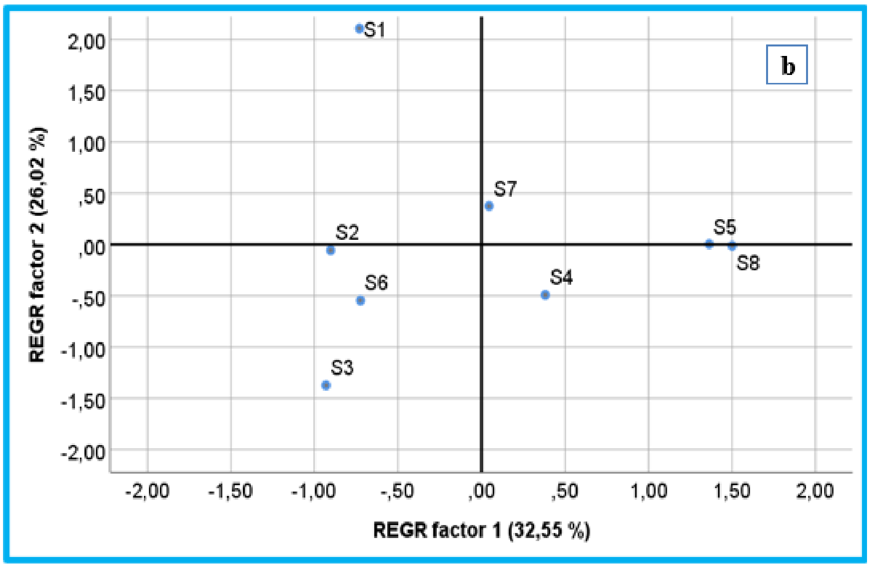

Figure 2: a) factorial and b) spatial representation of the physico - chemical parameters analysed in the natural waters of the Lac Léré basin

Variation in hydrochemical properties: The Piper and Schoeller - Berkallof diagrams shown in Figures 3a and 3b reveal two chemical facies: the first facies is bi/carbonate magnesian and calcic and the second is sulphate magnesian and calcic. The waters can be classified into three main groups according to their hydrochemical properties. The first group consists of two sites, S1 and S3, dominated by carbonate followed by sulphate; the second group consists solely of station S2, dominated by the presence of sulphate followed by bicarbonate; and the final group includes sites S4, S5, S6, S7 and S8, dominated by sulphate followed by nitrate. Finally, analysis of the Riverside diagram (Figure 3c) shows that the results obtained all belong to the zone of low sodium content and low electrical conductivity.

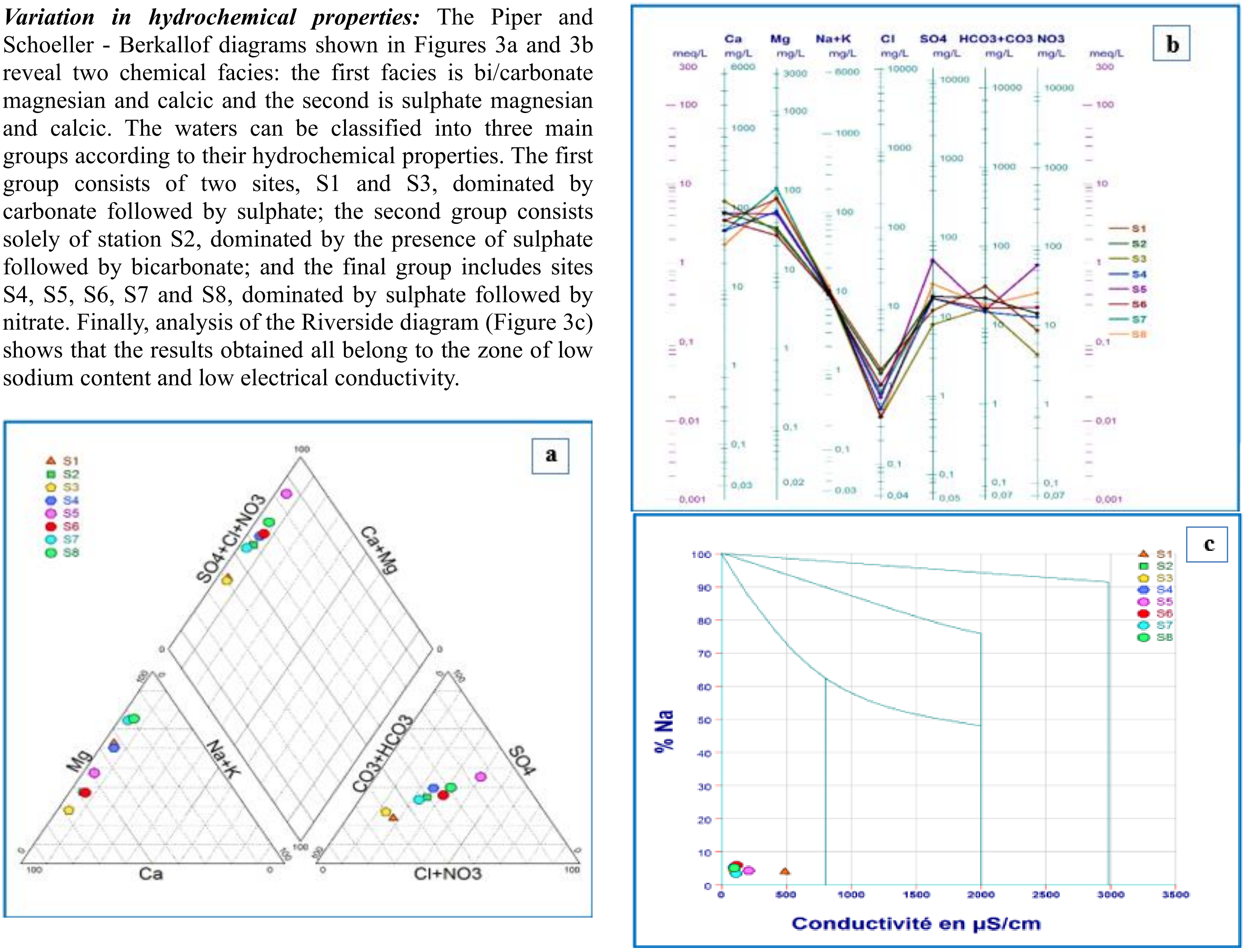

Figure 3: Surface water diagrams for the Lac Léré basin. a) Piper diagram, b) Schoeller - Berkallof diagram and c) Riverside diagram

3.2 Discussion

Physical parameters (T, pH and EC): Temperature, pH and electrical conductivity are the parameters used to assess the physical and chemical quality of water. The results showed that the surface waters of the Lake Lere basin have temperature values above the WHO range. The solubility of oxygen in water depends on temperature variation. In fact, it decreases when the temperature rises (R. Sébastien, 2014). Temperature plays an important role in the development of microbial life (B. Batoul, 2018). The rise in temperature causes the decomposition of carbonate, which then produces the carbon dioxide responsible for the change in pH of the water. The water in Lake Lere is neutral (average pH 6.9) and low in mineral content (average conductivity 166.03 µS/cm). The pH and electrical conductivity comply with WHO standards. However, the high conductivity was obtained at station S1. This rise in conductivity at this level may be linked to the solubilisation of minerals from agricultural activities along El - Ouaya. Others (F. Benrejdal and H. Ghoualem, 2015) obtained a very low electrical conductivity in rainwater in the Tizi - Ouzou region of Algeria, and this water has an acidic tendency compared with water from the Lac Lere basin. This result justifies the fact that rainwater is generally less loaded with mineral salts than surface water. The minerals in surface water most often come from human activities and run - off. However, the water from the lake at the Kossou hydroelectric dam on the Bandama river in Côte d'Ivoire has similar physico - chemical characteristics to our own (N. Koné, 2022). While the waters of Lake Lere and the Kossou dam have low electrical conductivity, this is not the case for the thermomineral surface waters of the Monts de la Cheffia in Algeria (H. Alayat and C. La Mouroux, 2007). The physico - chemical properties of water depend on the geological formation, the nature of the catchment areas and the surrounding human activities (J. P. Vicat, 2023).

Chemical parameters: The results of mineral analysis show that concentrations comply with the recommended standards for most of the sites studied.

Nitrate NO_3^{-}: Nitrate is the result of the chemical combination of nitrogen and oxygen. This inorganic compound is the result of a series of highly complex chemical reactions involving nitrogen compounds (proteins, ammonia, amino acids, oxides, etc.). (H. Haddad and H. Ghoualem, 2014) found similar nitrate levels in the waters of Algeria's coastal catchment. However, nitrate levels were abnormally high at station S5. This rise in nitrate concentration at this level may be due to the use of fertilisers in agriculture along the Mayo - Binder. (S. Mouissi and H. Alayat, 2016) explain in their work that nitrates in the water come from the mineralisation of biomass in the lake and the oxidation of ammoniacal nitrogen and nitrites.

Sulphate SO_4^{2-}: Sulphur combines with oxygen to give the sulphate ion, present in certain minerals such as gypsum and baryte. Sulphate can exist in water at a highly variable level, depending on the composition of the solid materials present in the water. The results show that the average concentration of sulphate analysed is very low compared with the admissible limit for sulphate, i. e.2500 mg/L (WHO) and 400 mg/L (Algerian standard). However, very high concentrations of sulphate were found by [18]. In the waters of Algeria's coastal watershed. Some authors attribute the sharp increase in sulphate content in water to industrial discharges and domestic wastewater (C. E. Delisle and J. W. Schmidt, 1977).

Phosphate PO_4^{3-}: Phosphate ions are responsible for the eutrophication of lake environments (L. Gouaidia, 2008), one of the main phenomena responsible for the deterioration of surface water quality (W. Ayad, 2017). Phosphate concentrations in the water of Lake Lere comply with WHO standards (5 mg/L) at sites S2, S5 and S8, and exceed the admissible threshold at stations S1, S3, S4, S6 and S7. According to some authors, the origin of phosphate emissions is linked to soil leaching and biomass combustion (F. S. Zhuang, 1997). Phosphate ions also come from the dissociation of mineral fertilisers used in agriculture.

Bicarbonate HCO_3^{-}: Carbonate precipitation at lake level depends on CO_2 content and pH (S. Mouissi and H. Alayat, 2016). However, when temperature increases, carbonates decompose to release the CO_2 responsible for the pH variation. The results show that the carbonate concentrations obtained in the water of Lake Lere are very low compared with the recommended standards, which is 150 mg/L. There is therefore no risk of pollution due to the presence of carbonate ions. Bicarbonates, associated with sulphates, are more dominant in Maestrichtian groundwater in the Biskra region of Algeria (F. L. Bouchemal and S. Achour, 2015).

Chloride Cl^{-}: while the waters of Lake Lere contain chlorides in very low concentrations compared with the prescribed standards, the values exceed 1400 mg/L in the Maestrichtian groundwater of the Biskra region in Algeria (L. Bouchemal and S. Achour, 2015). The presence of chloride ions in water depends on the lithology and geological formation of the environment studied. It is most often associated with alkali metals (Na, K) and alkaline earth metals (Ca, Mg). The sharp increase in Cl - content in water is generally linked to the discharge of industrial and domestic wastewater.

Silica SiO_2: this is a compound resulting from the association between a silicon atom and two oxygen atoms. Silica is present in water as a result of soil erosion. Silica exists in water in a free state in crystalline or amorphous form. However, crystalline silica is toxic and highly carcinogenic. Consumption of water containing crystalline silica can therefore cause silicosis, emphysema and lung cancer in humans (A. Radauceanu, 2019). The results show that concentrations are relatively low in the waters of the Lake Lere basin compared with the admissible limits (200 mg/L). However, the highest concentration is obtained at site S5 which would be due to thermal cracking of inorganic materials along the Mayo - Binder.

Sodium Na^{+} *and potassium* K^{+}: Regardless of the site studied, the sodium and potassium concentrations analysed in the surface waters of the Lake Lere basin are below the recommended standard (12 mg/L for Na and 200 mg/L for K). In their studies on the physico - chemical characteristics of rivers in Côte d'Ivoire, (A. Iltis and C. Lévêque, 1982) found sodium (3.3, 3.7 and 2.3 mg/L) and potassium (3.2, 1.9 and 2.2 mg/L) concentrations in the water of rivers in the north of Côte d'Ivoire, levels in the Haute Comoe, Bagoe and Leraba respectively are very similar to those we obtained in the waters of the Lake Léré basin. Alkali metal levels do not vary much naturally in surface waters. The sharp increase in Na and K in the water is due to anthropogenic activities.

Calcium Ca^{2+} and magnesium Mg^{2+}: Calcium has a high concentration that exceeds the admissible threshold at site S3 (120.4 mg/L). The concentrations obtained at the other sites comply with the recommended standards for calcium, i. e.100 mg/L. The site represents the load of pollutants from the town of Lere. Limestone from the demolition of houses and used porcelain materials could be linked to the increase in concentration at this level. As for magnesium, this metal coordinates the centre of the chlorophyll complex. The results show that 62.5% of the sites (S1, S4, S5, S7 and S8) have Mg concentrations above the recommended standards (50 mg/L). This high variation in Mg concentrations at these sites could be explained by the decomposition of the algae as a result of the rise in water temperature. Low concentrations of Ca (53.55 mg/L) and Mg (27.84 mg/L) compared with ours have been recorded in surface waters in a mining environment in west - central Côte d'Ivoire (K. S. A. Yao and K. E. Ahoussi, 2020). Mining activities make little contribution to calcium and magnesium emissions, except for limestone processing industries such as cement works, which can generate calcium in the environment.

Principal component analysis: This analysis shows four main classes of water based on physico - chemical properties. The first class includes sites S5 and S8, which express the alkalinity of the water through the action of nitrate and sulphate ions on alkali metals in the presence of dissolved silica. The second class includes sites S2, S3 and S6, characterised by pollution linked to agricultural activities and limestone processing. The third class of water is made up of sites S4 and S7. This class expresses the influence of the thermal process on the evolution of minerals. Finally, the last class is formed by S1, which characterises mineralisation followed by the dissociation/precipitation equilibrium of the carbonate present in the water. (S. Mouissi and H. Alayat, 2016) obtained higher percentages of variance than ours (F1: 40.12% and F2: 29.65%) in the waters of Lake Oubéira in the extreme north - east of Algeria. Their analyses were used to characterise organic pollution, mineralisation and the presence of colloids in the form of silicate compounds.

Chemical facies: The hydrochemical properties of the water in the Lake Lere basin were determined by constructing various diagrams (Piper, Schoeller - Berkallof and Riverside).

The bi/carbonate magnesian and calcic and sulphate magnesian and calcic facies probably reflect the lithology and geological formation (E. Kadjangaba, 2016**)** as well as the chemical nature of the catchment areas. The predominant presence of sulphate ions followed by nitrate could reflect agricultural inputs. The presence of alkaline earth ions may be due to mineral exploitation and to the decomposition of microflora. However, the results presented in the Riverside diagram show that the water in the Lake Lere basin is of excellent quality for irrigation. These waters contain fewer mineral salts that can disrupt the texture and ion exchange capacity of the soil.

4. Conclusion

This study assessed the physico - chemical and hydrochemical quality of surface waters in the Lake Lere basin. Results indicate compliance with most recommended water quality standards. The identified chemical facies—bicarbonate - calcium - magnesium and sulfate - calcium - magnesium—reflect geological and agricultural influences. Given the low mineral salt content and low electrical conductivity, the water in Lake Lere is deemed excellent for agricultural use. Future research should focus on seasonal variations in water quality to further assess long - term sustainability.

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Conflict of Interest
The Authors declare no conflict of interest.

References

[1] H. Alayat, C. La mouroux, Caractérisation physico - chimique des eaux thermo - minérales des Monts de la Cheffia. GEO - ECO - MARINA. (2007) 13/2007
[2] W. Ayad, Evaluation de la qualité physico - chimique et bactériologique des eaux souterraines: cas des puits de la région d'El - Harrouch (Wilaya de Skikda). Thèse de Doctorat. Université Badji Mokhtar – Annaba. Algérie. (2017), 156 p.
[3] O. Baldal, B. David, M. Djetarem, Étude sur les Ressources minières et pétrolières dans le Mayo Kebbi Ouest, Tchad. *Rapport de mission (*2013), 98p.
[4] B. Batoul, Contribution à l'étude de la contamination des eaux et des sédiments de l'Oued Cheliff (Algérie). Thèse de Doctorat. Université de Perpignan via Domitia. (2018), 192 p.
[5] F. Benrejdal, H. Ghoualem, Contribution à la caractérisation physicochimique des eaux de pluie de la région de Tizi - Ouzou traitement par filtres plantés. *Larhyss Journal, (*2015), ISSN 1112 - 3680, n°23, 41 - 52.
[6] F. L. Bouchemal, S. Achour, Qualité physico - chimique et paramètres de pollution des eaux souterraines de la région de Biskra. *Larhyss Journal, (*2015) *n°22, 197 - 212.*
[7] C. E. Delisle, J. W. Schmidt, The effect of sulfur on water and aquatic life in Canada. Sulfur and its inorganic derivatives in the Canadian environment, *NRCC, N°15015*, Centre National des recherches du Canada, Ottawa (1977).
[8] L. Gouaidia, Influence de la lithologie et des conditions climatiques sur la variation des paramètres physico –chimiques des eaux d'une nappe en zone semi - aride, cas de la nappe de Meskiana Nord - Est Algérien ». Thèse de doctorat. Université Badji Mokhtar - Annaba. Algérie (2008), 199 p.

[9] H. Haddad, H. Ghoualem, Caractérisation physico - chimique des eaux du bassin hydrographique côtier Algérois. *Larhyss Journal, (*2014), ISSN 1112 - 3680, n°18, 155 - 167.
[10] A. Iltis, C. Lévêque, Caractéristiques physico - chimiques des rivières de Côte d'Ivoire. *Rev. Hydrohiol. Trop, (*1982), 15 (2) 115 - 130.
[11] E. Kadjangaba, D. Djoret, M. J. C. Doumnang, G. A. Ndoutamia, Y. Mahmout, Impact des Processus Hydrochimique sur la Qualité des Eaux souterraines de la Ville de N'Djaména - Tchad. *European Scientific Journal, (*2018), 14 (18): 1857 – 7881.
[12] P. Kedeu, Origine structurale et fondements géologiques du décalage géographique des lacs de Léré et Tréné: essai de synthèse. *Revue des Lettres, Langues et Sciences de l'Homme et de la Société, (*2021), 11 (1) 405 - 417.
[13] N. Koné, A. S. N'DA, K. B. Kien, G. F. H Boguhé, S. Berté, Caractérisation physico - chimique des eaux du lac du barrage hydroélectrique de Kossou, fleuve Bandama, Côte d'Ivoire. Rev. Ivoir. Sci. Technol., 39 (2022) 55 – 69.
[14] S. C. Louise, Analyses des affluents des lacs de la municipalité de Saint Faustin Lac - Carré printemps, *Rapport* (2008), 48p.
[15] S. A. M. Mahamat, T. Maoudombaye, T. Abdelsalam, G. Ndoumtamia, B. Loukhman, Évaluation de la qualité physico - chimique des eaux d'adduction publique de la Société Tchadienne des Eaux à N'Djamena au Tchad. *Journal of Applied Biosciences* 95 (2015), 8973 – 8980.
[16] S. Mouissi, H. Alayat Utilisation de l'Analyse en Composantes Principales (ACP) pour la Caractérisation Physico - Chimique des Eaux d'un Ecosystème Aquatique: Cas du Lac Oubéira (Extrême NE Algérien). *J. Mater. Environ. Sci. (*2016), 7 (6) 2214 - 2220.
[17] D. Nadjiam, Les ressources en sols du Tchad les actions prioritaires pour une gestion durable. Accra, Ghana. *Rapport (*2013), 15 p
[18] NASA. http: //www.nasa. agroclimatology_data. org (site consulté le 02 août 2024).
[19] N. Ngaram, N. M. Tchadanaye, A. Merle, P. Bauteri, B. A. N. Baskali, Caractérisation physico - chimique des eaux du fleuve Chari au niveau de la ville de N'Djaména (Tchad). *Anales de l'université de N'Djaména - Série C –N°05, (*2011), *102 p.*
[20] Planétoscope, *©2012 planetoscope. com. Statistique Eaux, 2024 (*Site consulté le 6 août 2024).
[21] A. Radauceanu, Y. Guichard, M. Grzebbyk, Toxicité des silices amorphes nanostructures: état des connaissances et intérêt des biomarqueurs d'effets précoces dans la recherche. *INRS, TP,* France (2019) 36 p.
[22] J. Rodier, L. Bernard, N. C. Merletet, *L'analyse de l'eau pour statistique*.9e édition Dunon Paris (2009), 5600p.
[23] R. Sébastien, G. Gaëlle, S. Ana, Diagnostic environnemental du Lac Sergent: caractérisation des sédiments et qualité de l'eau de surface. Université Laval. Québec. *Rapport* (2014), 46 p.
[24] T. Souareba, J. C. Doumnang, P. Rondouba, M. Tarkodjiel, Y. Mahmout, Evaluation de la contamination par les métaux lourds (Al, Fe, Mn, Ni, Zn, Cr, Cd et Pb) des sédiments du bassin du lac Léré, Mayo - Kebbi Ouest, Tchad. *Int. J. Biol. Chem. Sci.* (2024), 18 (2) 723 - 736. Doi: https: //dx. doi. org/10.4314/ijbcs. v18i2.31
[25] J. P. Vicat, M. J. C. Doumnang, D. N. Nadjilem, Physicochemical Caraterisation o Pond Waters in the Kanem Region, Republic of Chad. *International Journal of Multidisciplinary Research and Publications (IJMRAP), (*2023) 6 (4) 68 - 75.
[26] K. S. A. Yao, K. E. Ahoussi, Caractérisation Physico - Chimique Des Eaux De Surface Dans Un Environnement Minier Du Centre - Ouest De La Côte d'Ivoire: Cas Du Département De Divo. *European Scientific Journal, (2020) Vol.16, No.12 1857 - 7881.* Doi: 10.19044/esj.2020. v16n12p293.
[27] F. S. Zhuang, J. Ma, Y. P. Cao, Phosphorus deficiency enhances root exudation of low - molecular weight organic acids and utilization of sparingly soluble inorganic phosphates byradish and rape plants. *Plant and Soil* (1997), 196, 261 - 264.