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RESEARCH ARTICLE

CONTRIBUTION TO THE ESTIMATION OF SOME MAJOR IONS AND MINERALS IN SURFACE SEDIMENTS OF THE LAKE LERE BASIN, MAYO-KEBBI WEST (REPUBLIC OF CHAD)

Jean-Claude Doumnang Mbaigane[1,3], Tchinfanbe Souareba[1,2,3] , Mahamat Nour Abdallah[3] and Mianpereum Tarkodjiel[2]

1. Laboratoire de Geologie, Geomorphologie et Teledetection / F.S.E.A. Universite de N'Djamena BP 1027, Tchad .
2. Laboratoire de Recherche sur les Substances Naturelles, Universite de N'Djamena BP 1027, Tchad .
3. Laboratoire de Recherche en Hydro-Geosciences et Reservoirs, Universite de N'Djamena BP 1027, Tchad .

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Abstract

Subject to constraints linked to human activities and climate change, sediments in the Lake Lere basin have accumulated various inorganic materials. The objective of this study is to estimate the levels of several major ions and minerals, namely nitrate, sulphate, phosphate, carbonate,chloride,silica,calcium and magnesium,in the surface sedime nts of the Lake Lere basin. These ions were analysed in accordance with French standards after a series of physico-chemical treatments of the samples. The results showed that the concentrations of the different ions analysed varied from one ion to another and depended on the nature of the sites studied. The average concentrations (mg/kg) obtained are respectively: (17.75), (41.25), (61.05), (106.2), (2.81), (422.68), Ca^{2+} (849) and Mg^{2+} (636.11). According to these results, the levels of most minerals remain low compared to their concentration s in the geochemical reference background. However, phosphate levels are particularly high above the threshold. Consequently, the sediments of the Lake Lere basin are enriched in phosphate. Furthermore, principal component analysis made it possible to distinguish three groups of sites: G1 (S1, S4, S5 and S8), G2 (S2 and S3) and G3 (S6 and S7). Group G1 is enriched in nitrate, carbonate, sulphate and silica; group G2 is enriched in chloride and group G3 in phosphate, calcium and magnesium.

These results indicate that the minerals analysed interact with each other in the sediments and that they originate mainly from inputs from the catchment areas. Phosphate and nitrate are nutrients for plant growth; these minerals could be retained in sediments in various chemical forms. Consequently, their concentrations in sediments should be monitored to prevent any form of pollution through eutrophication. These nutrients are the subject of a possible study of their speciation in order to preserve the quality of the sediments in the Lake Lere basin.

Corresponding Author:-Doumnang Mbaigane Jean Claude
Address:-1. Laboratoire de Geologie, Geomorphologie et Teledetection / F.S.E.A. Universite de N Djamena BP 1027, Tchad .3. Laboratoire de Recherche en Hydro-Geosciences et Reservoirs, Universite de N Djamena BP 1027, Tchad .

Introduction:-

Industrial and agricultural activities are currently growing and intensifying in many Central African countries (Hazebrouck et al., 2021). As a result, environmental pollution, particularly in aquatic environments, is becoming a cause for concern. The most common consequences observed are the degradation of water and soil quality. Among the environments that receive pollutants, sediment stands out for its ability to accumulate various minerals and micropollutants (Mouyalou et al., 2019). When sediment is oversaturated with minerals, it can release metallic substances through acid digestion, which can make the environment toxic to biological systems (Casado et al., 2021). This could compromise its potential recovery due to the high cost of decontamination (Rofes et al., 1991; Ayah et al., 2012). However, Chad, a particularly landlocked country with no access to the oceans, is currently facing challenges related to water and soil quality. For more than a decade, Chad's lakes have been subject to anthropogenic activities and constraints linked to global warming, which have had a negative impact on water and sediment quality (Souareba et al., 2024).Another problem is that the Lake Lere basin, the subject of the study, located in the far south-west of the country, is an area of intense agricultural activity (fertilisers and pesticides), mineral exploitation (gold, limestone, gypsum, etc.), quarrying (sand, gravel, laterite, clay, etc.) and transhumance (Nadjiam, 2013).

The Baore cement plant, located upstream of the basin's water supply system, which has been producing cement for over a decade, is a typical example of a mining industry that generates inorganic micromaterials. Currently, the Lake Lere basin is subject to environmental constraints due to erosion and changing climatic parameters (Souareba et al., 2024) . Nevertheless, this basin is crossed by the permanent watercourse, the Mayo-Kebbi, and fed during the rainy season by the Mayo-Binder and El-Ouaya. Studies show that the lake has been considerably reduced in depth, from an average of 14 m in 1993 to 4 m today (Levêque, 1971; 2019). It is filling up downstream with material from the Mayo-Binder and upstream with material from the El-Ouaya, which then cuts off the connection between the two lakes of Lere and Trene (Kedeu, 2021).However, this phenomenon of filling of the Lere basin is currently characterised by overflowing water levels, which then leads to flooding that has consequences for socio-economic activities and the health of coastal populations. Geological (Doumnang, 2006) and geomorphological (Passinring, 2006) studies also reveal that the Lere Lake basin is rich in significant mineral potential. The objective of this article is to evaluate the physico-chemical parameters, particularly the major ions and minerals in the surface sediments of the Lere Lake basin. This study is part of an effort to build a database on these elements with a view to potentially exploiting the sediments in this basin on the one hand, and understanding the mechanism of water and sediment quality degradation on the other.

Materials and Methods:-

Materials:-

Geographical context of the study area:-

Administratively, Chad consists of 23 provinces, one of which is Mayo-Kebbi West, located in the south-west of the country. Lake Lere is one of the five departments of the Mayo-Kebbi Ouest province. It is located between 9° and 9.37° north latitude and 14° and 14.17° east longitude. Lere is the 19th most populous city in Chad. Its population was estimated at 12,600 in 1993, 226,000 in 2009 and more than 650,000 today, with more women than men (INSEED, 2009). The population's activities are mainly based on agriculture, livestock farming, trade, fishing and crafts. The Lake Lere Department, like the greater south-west of Chad, has a tropical climate characterised by a single, short rainy season from May to October, with annual rainfall varying from around 400 to 1,200 mm over the last 30 years (NASA, 2024). Lere experiences a harsh and long drought with maximum temperatures hovering around 45°C. The Lake Lere basin is bordered by mountain ranges with rugged and particularly picturesque shapes (Doumnang, 2006).It is occupied in the centre by a plain, dotted with a few granite hills. In terms of soil, the soils are loamy and rich in alluvium along the watercourses. However, there are also clayey and sandy soils in the large lacustrine plain of the basin (Baldal et al., 2013).

Sampling and sample preparation:-

Surface sediments (between 0 and 15 cm deep) were collected from 24 locations using special equipment designed for sample collection. The samples were collected by pirogue, accompanied by a fisherman, from a motorised boat. Once collected, the samples were carefully labelled and placed in polyethylene plastic packaging. The samples were transported to the Hydrogeosciences and Reservoirs Research Laboratory for analysis. Dried at room temperature, the samples were quartered, crushed and sieved. The 24 samples were thus prepared to obtain a final total of eight representative samples (Rodier et al., 2005; 2009).

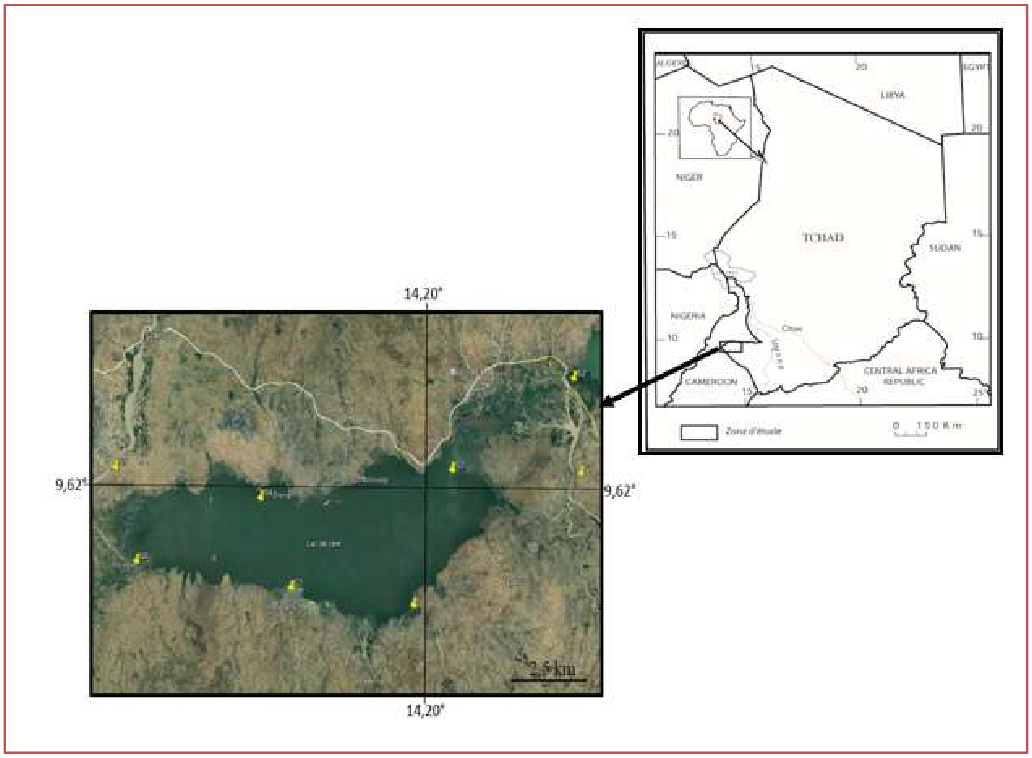


Figure 1: Geolocation map of the study area and sampling sites.

Methods:-

Extraction and analysis of ions and minerals:-

5 g of each sediment sample was placed in a 100 ml Erlenmeyer flask containing 50 ml of a 1 mol/L ammonium acetate solution. The mixture was homogenised using a magnetic stirrer for 1 hour and then filtered using Wattman filter paper into a 100 ml flask. The volume was adjusted to 100 ml with demineralised water and finally filtered through a cellulose membrane (Maynard, 1970). The samples obtained were subjected to spectrophotometric analysis of minerals according to the methods described in Table 1 (Rodier et al., 2005; Wang et al., 2010). The concentrations of anions measured in mg/L were then converted to mg/kg of dry sediment using the following formula:

$$[\mathrm{mg/kg}] = \frac{[\mathrm{mg/L}]_{\mathrm{mes}} * 1000}{\frac{5\mathrm{g}}{100\ \mathrm{mL}} * 1000}$$

- $[\mathrm{mg/L}]_{\mathrm{mes}}$ is the concentration measured during analysis;
- 1000 in the numerator results from the conversion of g to kg: 1 kg = 1000 g;
- 1000 in the denominator results from the conversion of 1 mL to L: 1 L = 1000 mL;
- 100 mL represents the volume in which the 5 g of sediment were dissolved.

Table 1: Summary of methods and devices for measuring minerals.

Minerals studied	Device and methods
Nitrate, sulphate, phosphate and silica	Spectrometric method using the HACH-LANGE Link2SC DR 3900 spectrophotometer.
Carbonate, chloride, calcium and magnesium	Titrimetric method using the HACH-SI Analytics automatic titrator

Data analysis and statistical processing:-

The histograms were constructed using Microsoft EXCEL version 2013. Principal component analysis and analysis of variance (ANOVA) were performed using IBM SPSS statistics software version 25.

Results and Discussion:-

Results:-

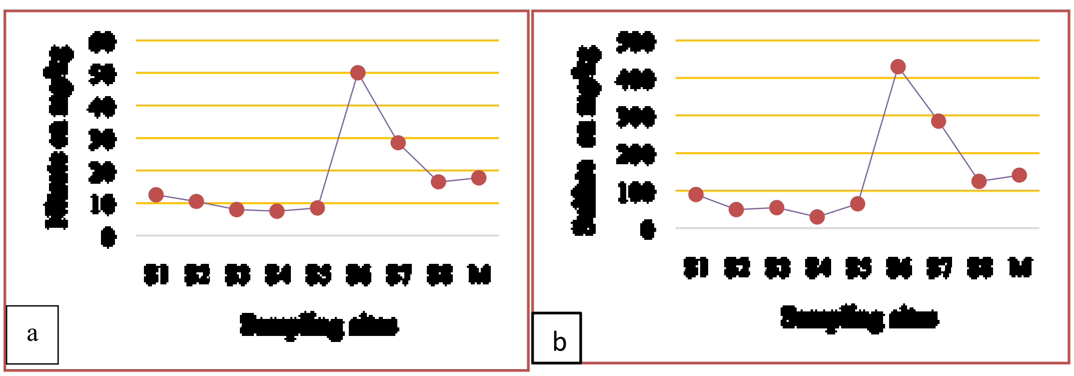
Variation in chemical elements content:-

The results presented in Figures 2a, 2b, 2c, 2d, 2e, 2f, 2g and 2h show that the ion and silica contents analysed in the sediments of the Lake Lere basin vary according to the sampling sites and are mostly lower than the contents in the geochemical background of the continental crust.

The nitrate content varies from 7.5 (S4) to 50 mg/kg downstream (S6) with an average of 17.75 mg/kg. This variation is significant at a 95% level. The nitrate content recorded upstream (S2) is 10.5 mg/kg (Figure 2a). The sulphate content varies from 30 (S4) to 430 downstream (S6) with an average of 41.25 mg/kg. The sulphate content recorded downstream is 50 mg/kg. This variation is highly significant at a 99% level (Figure 2b). The carbonate content varies from 23.5 mg/kg upstream (S2) to 358 mg/kg downstream (S6), with an average of 106.2 mg/kg. This variation is significant at a 95% level (Figure 2c).

The chloride content varies from 1.25 mg/kg downstream (S6) to 4.75 mg/kg (S5), with an average of 2.81 mg/kg. This variation is not statistically significant. The chloride content recorded upstream is 3.25 mg/kg (Figure 2d). The phosphate content varies from 4.1 (S5) to 196.6 mg/kg upstream (S2) with an average of 61.05 mg/kg. This variation is highly significant at a 99% confidence level. The phosphate content recorded downstream is 70 mg/kg (Figure 2e). The silica content varies from 79 (S4) to 1692.5 mg/kg downstream (S6) with an average of 422.68 mg/kg. The silica content recorded upstream is 122.5 mg/kg. The variation in silica content is highly significant at a 99% confidence level (Figure 2f). The calcium content varies from 516 (S8) to 1462 mg/kg upstream (S2) with an average of 849 mg/kg. The content recorded downstream is 946 mg/kg. The variation in calcium content is not significant (Figure 2g).

The magnesium content varies from 247.98 (S8) to 1341.6 mg/kg upstream (S2) with an average of 636.11 mg/kg. The recorded content downstream is 802.38 mg/kg. The variation in Mg content is not statistically significant (Figure 2h).



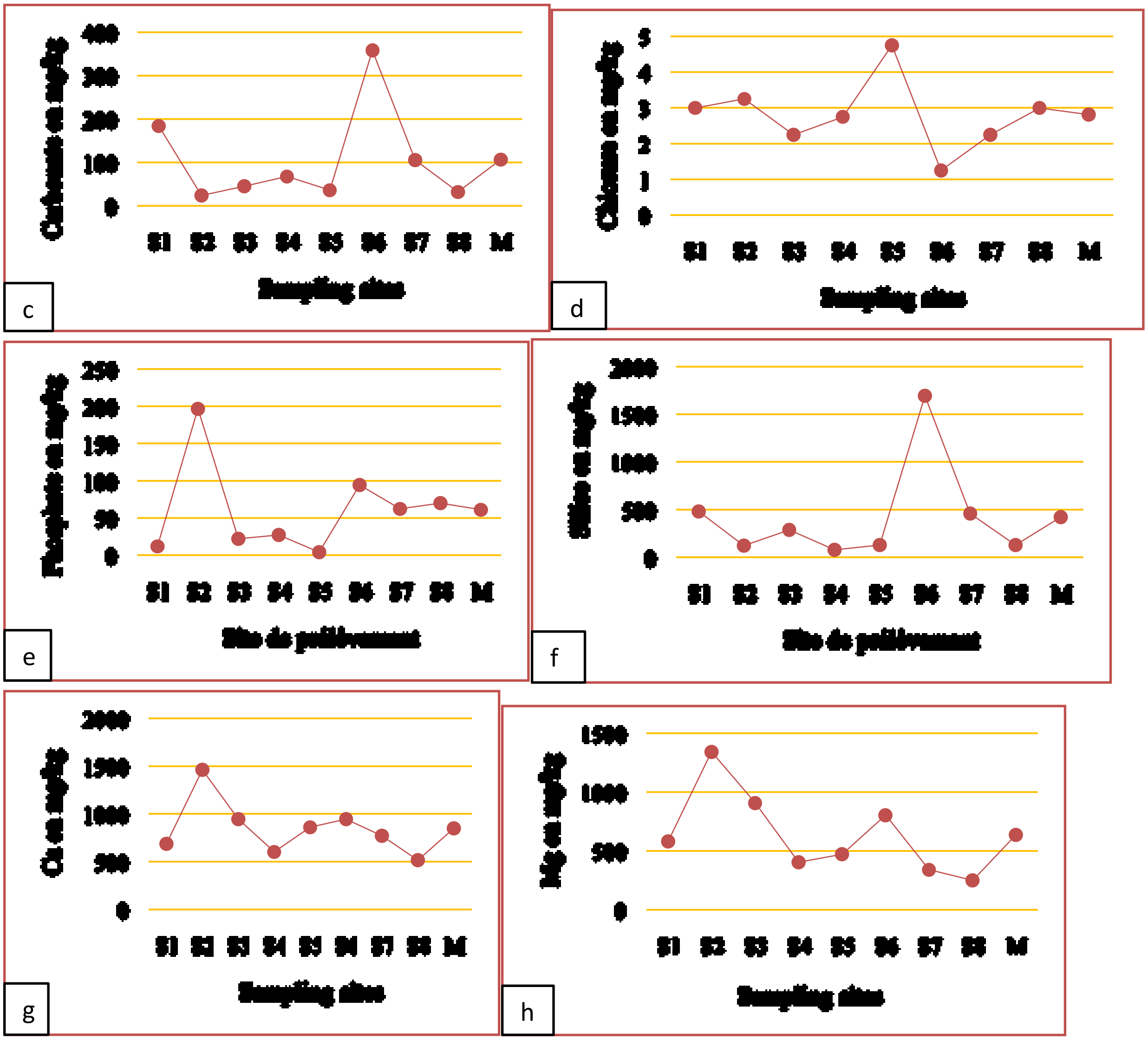


Figure 2: Variation in the concentrations of elements analysed in sediments from the Lake Lere basin according to location: a) Nitrate; b) Sulphate; c) Carbonate; d) Chloride; e) Phosphate; f) Silicate; g) Calcium and h) Magnesium.

Principal component analysis:-

Table 2 shows the correlation matrix between the mineral compounds analysed in sediments from the Lake Lere basin. Only significant correlations (positive or negative) are interpreted and are shown in bold. According to Table 2, nitrate correlates positively with sulphate (coefficient 0.99), carbonate (coefficient 0.84) and silica (coefficient 0.92) and negatively with chloride (coefficient -0.69). Sulphate correlates positively with carbonate (coefficient 0.81) and silica (coefficient 0.88) and negatively with chloride (coefficient -0.67). Carbonate correlates negatively with chloride (coefficient -0.65) and positively with silica (coefficient 0.95). Chloride correlates negatively with silica (coefficient -0.70). Phosphate correlates positively with calcium (coefficient 0.73) and magnesium (coefficient 0.66). Finally, calcium correlates positively with magnesium (coefficient 0.93). Table 3 shows the variance in information explained by the principal components. Thus, 100% of the information is extracted and explained by the first seven components. Approximately 85.87% of the information is explained by the first two components, with component 1 accounting for 53.66% and component 2 accounting for 32.21% of the total variance. However, components 3 to 7 account for only a small proportion of the variance (approximately 14.13%). The results presented in Figures 3 and 4 show that the first component of the factorial plan groups together nitrate, carbonate, sulphate and silica, which are associated with sites S6 and S7, in its positive part, and chloride, which is associated with sites S1, S4, S5 and S8, in its negative part. The second component groups together only minerals such as phosphate, calcium and magnesium in its positive part, which coincide perfectly with sites S2 and S3.

Table 2: Correlation matrix between the elements analysed in the sediments of Lake Lere basin.

		NO3	SO4	CO3	Cl	PO4	SiO2	Ca	Mg
Correlation	NO3	1,00							
	SO4	**0,99**	1,00						
	CO3	**0,84**	**0,81**	1,00					
	Cl	**-0,69**	**-0,67**	**-0,65**	1,00				
	PO4	0,24	0,17	0,01	-0,19	1,00			
	SiO2	**0,92**	**0,88**	**0,95**	**-0,70**	0,12	1,00		
	Ca	0,02	-0,02	-0,04	0,02	**0,73**	0,08	1,00	
	Mg	-0,02	-0,09	0,04	-0,12	**0,66**	0,14	**0,93**	1,00

Values in bold are statistically significant at a 95% level (P<0,05).

Table 3: Total variance explained by the first seven components of the factorial design representing the few elements analysed in the sediments of Lake Lere basin.

Component	Initial eigenvalues			Sums extracted from the load square			Sums of rotation from the load square		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4,32	54,08	54,08	4,32	54,08	54,08	4,29	53,66	53,66
2	2,54	31,80	85,88	2,54	31,80	85,88	2,57	32,21	85,88
3	0,51	6,45	92,34						
4	0,45	5,66	98,00						
5	0,13	1,71	99,72						
6	0,01	0,24	99,96						
7	0,00	0,03	100,00						

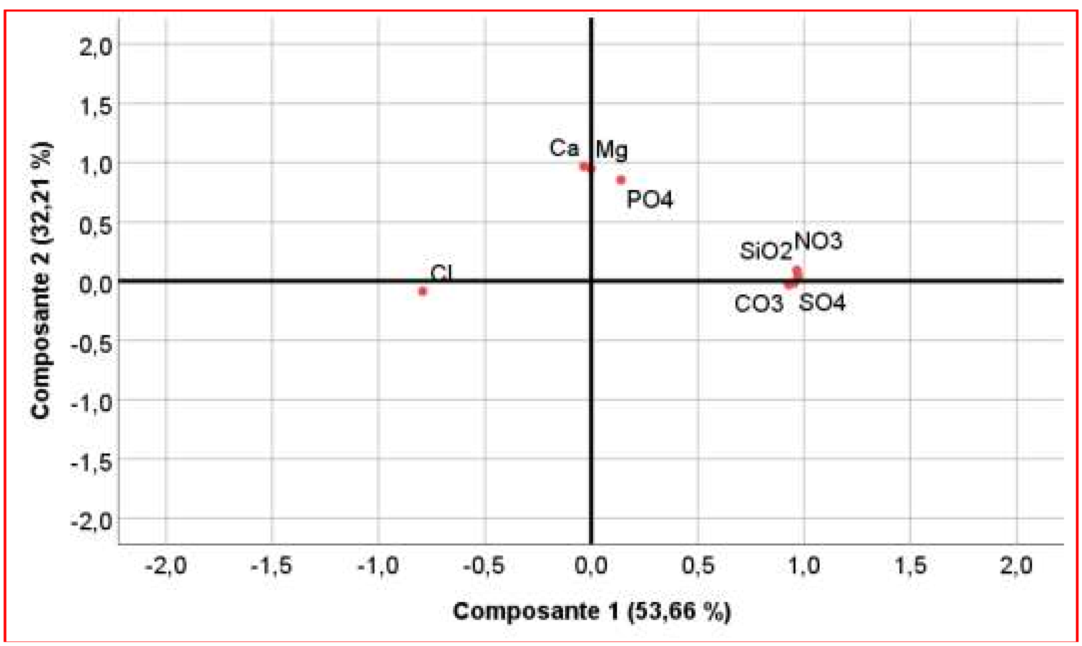


Figure 3: Factorial representation of ions and elements analysed in sediments from the Lake Lere basin.

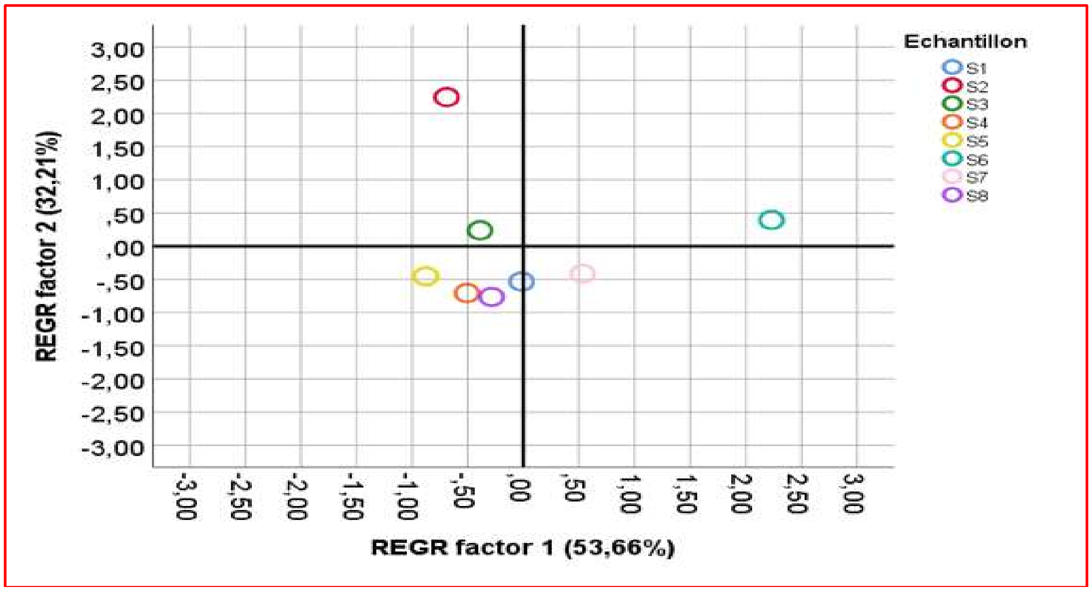


Figure 4: Spatial representation of the contribution of the elements analysed at the various sites in the Lake Lere basin.

Discussion:-

Variations in content depend on the nature of the compound analysed and the sites studied. Let us examine each of the minerals analysed in the Lake Lere basin, namely:
nitrate, sulphate, phosphate, carbonate, chloride, silica, calcium and magnesium.

Nitrate: Nitrate comes mainly from chemical fertilisers. It is also the result of a series of oxidations of nitrogenous organic matter. Its content in the soil is around 20,000 mg/kg. The high nitrate content obtained at sites S6 and S7 may be due to agricultural activities along the Mayo-Binder. During the physico-chemical characterisation of dredged sediments from the port of Owendo in Gabon for the purpose of their recovery, Mouyalou et al. (2019) found a low concentration of nitrate (0.5 mg/kg dry soil) in the dredged sediments compared to the levels in the sediments of the Lake Lere basin. The strong correlation between nitrate and sulphate, carbonate, silica and chloride may be the result of anthropogenic activities and the geology of the catchment areas.

Sulphate: Anthropogenically, sulphates come from household waste and used batteries (Emilien, 2008).
nitrate, sulphate, phosphate, carbonate, chloride, silica, calcium and magnesium.
However, they may also result from the natural dissociation of sulphate minerals, the main ones being gypsum ($CaSO_4.nH_2O$) and barite ($BaSO_4$). There is a low sulphate content in the sediments of the Lake Lere basin compared to that of the reference bottom (20,000 mg/kg dry sediment) (INRAE, 2013). However, unlike ours, a high sulphate content (2530 mg/kg dry sediment) was found in dredged sediments used as alternative material in the English Channel (Saussaye et al., 2012).

Phosphate: The main phosphate minerals are apatite ($Ca_5(PO_4)_3(OH, Cl, F$) and monazite $(Ce, La, Y, Th)PO_4$). According to Aissaoui (2017), variations in phosphate content in sediments may result from anthropogenic inputs and erosion of the soils that make up the catchment area. The results show that sediments in the Lake Lere basin contain high average levels of phosphate. 75% of the sites analysed have levels above the geochemical background (23 mg/kg). Site S2 is identified as having the highest phosphate content. However, a phosphate content (40 mg/kg) similar to ours was recorded in deep soil (between 300 and 400 cm) in Lyon, France, during a study of the role of vegetation on the evolution of the physicochemical characteristics of sediments deposited in a rainwater infiltration basin (Bedell et al., 2013). In contrast, in soil without vegetation, the authors obtained a content of around 1500 mg/kg (Badin, 2009). Phosphate is a vital nutrient for plants, which is why its concentration in soil or sediments must be influenced by vegetation (Couvida, 2015). In the Lake Lere basin, phosphate is influenced by calcium and magnesium. This explains why these minerals are involved in the formation of inorganic complexes in the soil.

Carbonate: Carbonate minerals such as calcite ($CaCO_3$), siderite ($FeCO_3$) and dolomite ($CaMgCO_3$) are mainly found in the soil. The highest carbonate content analysed in the sediments of the Lake Lere basin reached 350 mg/kg at site S6, a point located downstream of the lake. Carbonates are unstable in sediments and can spontaneously transform under variations in temperature and pH. Souareba et al. (2024) showed that the water temperature in the middle of Lake Lere was very high (30.8°C), which means that carbonates can decompose into CO2, causing the environment to become acidic. Badin (2009) found a carbonate content of 162,000 mg/kg in vegetation-free soil in La Manche, France. At the same location, Bedell (2013) obtained a content approximately twice as high as that obtained by Badin (2009). It should also be noted that the carbonates analysed in the Lake Lere basin are mainly influenced by chloride and silica.

Chloride: The main chloride minerals found in soil are rock salt (NaCl) and sylvite (KCl). However, chlorides also come from household waste and urban waste. Sediments in the Lake Lere basin contain low levels of chlorides, around 3 mg/kg, compared to the reference level for this mineral (15,000 mg/kg) (INRAE, 2013). The low concentration of chlorides in the bottom of Lake Lere may be linked to the geology of the catchment basins, but also to the nature of anthropogenic activities. However, a very high chloride content (11,403 mg/kg) compared to ours was found in dredged sediments at the port of Owendo in Gabon (Mouyalou et al., 2019).

Silica: Silica results from the combination of oxygen atoms surrounding the silicon atom. Silica is thought to result from the alteration of the main silicate minerals found in the soil: quartz (SiO_2), sillimanite (Al_2SiO_5), microcline (KAl_2SiO_5) and orthoclase ($KAlSi_3O_8$). The results indicate that the average silica content determined in the surface sediments of the Lake Lere basin is lower than the content in the reference soil (27,700 mg/kg). However, site S6 has a silica content of over 1,600 mg/kg, which is particularly high compared to the other stations. This increase in the mineral at this level may be due to inputs from the Mayo-Binder. Silica levels of 530 mg/kg upstream and 470 mg/kg downstream, similar to the average recorded in the Lake Lere basin, were found in the silt accumulated in port sites at the Port of Binic in Côtes-d'Armor (Clozet et al., 2000). Silica is the main constituent of the Earth's crust.

Calcium and magnesium: calcium and magnesium are involved in the formation of many soil minerals. Variations in calcium and magnesium content therefore depend on the chemical nature of the sediments studied (Casalet, 2012). The average levels recorded in the surface sediments of the Lake Lere basin are relatively low compared to the threshold value (3,630 mg/L for Ca and 2,000 mg/kg for Mg). Nevertheless, site S6 contains about twice the average recorded. This can be explained by the calcareous nature of the Mayo-Kebbi and the limestone mining and processing activities (Baore cement plant at Pala). Calcite (CaCO3) and dolomite (CaMgCO3) (the main constituents of limestone) are thought to be the most dominant minerals at this level, and their dissociation would release Ca and Mg into the sediments. Magnesium is thought to come from the weathering and dissolution of magnesian and ferromagnesian minerals, the main components of the basic and ultrabasic rocks that outcrop around Lake Lere (Doumnang, 2006). However, concentrations of 11.5 mg/kg and 13.7 mg/kg of Ca and Mg respectively in the form of metal oxides have been determined in dredged sediments from the port of Owendo (Mouyalou et al., 2019).

Conclusion:-

Several major ions and minerals were analysed in sediments from the Lake Lere basin. The aim was to assess the quality of these materials for possible recovery after dredging. The results indicate that the sediments contain low concentrations of major ions compared to the reference geochemical background.However, among the ions analysed, phosphate is the mineral with the highest concentration in the sediments, with a recorded content above the threshold. Sites S2 and S6 (representing the Mayo-Kebbi and Mayo-Binder flows, respectively) are considered to be the most potentially enriched in major elements. The results also show that most of the elements analysed belong to a well-defined group of sites and interact with each other. However, as phosphate and nitrate are essential nutrients for aquatic plants, they can be retained in sediments in various chemical forms. Consequently, their concentrations in sediments must be monitored in order to prevent any possible pollution through eutrophication.The surface sediments of Lake Lere exhibit variable concentrations of major ions and minerals. Phosphate enrichment is significant, posing environmental risks. PCA reveals site-specific mineral groupings, reflecting anthropogenic inputs and natural processes. Effective monitoring and management strategies are essential to preserve sediment and water quality in the basin.We therefore propose that these nutrients (phosphate and nitrate) be studied in terms of their speciation in the sediments of the Lake Lere basin so that measures can be taken to protect the fauna and flora of the Lake Lere basin.

Based on the results obtained, we propose the following actions in the future:
- Conduct continuous monitoring to prevent ecological degradation.
- Implement sediment quality monitoring programmes.
- Conduct studies on phosphate and nitrate speciation.
- Develop sustainable agricultural practices to reduce nutrient runoff.
- Assess the potential for reusing sediments for construction or soil improvement.

References:-

1. Aissaoui A., (2017).Evaluation du niveau de pollution des eaux et des sediments du barrage Hammam Grouz (Wilaya de Mila).Impact sur deux espèces de poisson Cyprinus carpio et Barbus setivimensis. Thèse de doctorat, Universite Mouloud Mammeri De Tizi-Ouzou. Algerie.
2. Ayah M., Bawa L.M., Djaneye-Boundjou G., Doni S.K., et Nambo P. (2012).Speciation du cadmium, du chrome, du cuivre et du plomb dans les sediments des dechets de phosphate de Kpeme (Sud-Togo)Int. J. Biol. Chem. Sci.6(1): 479-492 14 p. DOI: http://dx.doi.org/10.4314/ijbcs.v6i1.43
3. Badin A.L., (2009) -Repartition et influence de la matière organique et des microorganismes sur l'agregation et le relargage de polluants dans des sediments issus de l'infiltration d'eaux pluviales urbaines. Thèse INSA de Lyon. 231 p.
4. Baldal O., David B., Djetarem M., (2013).Etude sur les Ressources minières et petrolières dans le Mayo Kebbi Ouest, Tchad. Rapport de mission, 98p.
5. Bedell J-P., Saulais M., Delolme C. (2013). Rôle de la vegetation sur l'evolution des caracteristiques physico-chimiques des sediments deposes dans un bassin d'infiltration des eaux pluviales. Etude et Gestion des Sols, 20 (2), pp.27-38.halsde-00870023.
6. Casado C., Wildi M., Ferrari Benoît J.D., Werner I. (2021). Strategie d'evaluation de la qualite des sediments en Suisse. Etude elabore sur mandat de l'Office federal de l'environnement. Centre suisse d'eco-toxicologie appliquee, Lausanne.
7. Cazalet ML., (2012).Caracterisation physico-chimique d'un sediment marin traite aux liants hydrauliques : evaluation de la mobilite potentielle des polluants inorganiques. Thèse de doctorat. INSA de Lyon, France. 267 p.
8. Clozel B.,Breeze D., Crouzet C., Jezequel P., Pedroletti V., FPillard F. (2000). Approche methodologique de caracterisation physico-chimique des vases accumulees en sites portuaires, Port de Binic (Côtes-d'Armor). Service public du BRGM 98-E-207 180 p.
9. Coudray C., Decaeftecker B.,Menu S. (2022).Caracteristiques physico-chimiques des zones d'atterrissement et valorisation à terre des sediments fins de barrages. Colloque TSMR – CFBR « Transport sedimentaire : rivières & barrages reservoirs », Saclay, du 15 au 17 mars 2022.
10. Couvidat J., (2015). Gestion d'un sediment de dragage marin contamine : Caracterisation de la reactivite biogeochimique, valorisation en mortier et evaluation environnementale. Thèse de doctorat, Ingenierie de l'environnement. INSA de Lyon, France. 248 p.
11. Doumnang M.J.C., (2006).Geologie de formations neoproterozoiques du Mayo Kebbi (Sud-Ouest du Tchad) : apport de la petrologie et de la geochimie : implications sur la geodynamique au Panafricain. Thèse de doctorat, Science de la Terre et de l'Univers, Universite d'Orleans.
12. Emilien B. (2008), « Evolution de l'impact environnemental de lixiviats d'ordures menagères sur les eaux superficielles et souterraines, approche hydrobiologique et hydrogeologique ». Thèse de Doctorat. Universite de Franche-Comte. France. 249 p.
13. Hazebrouck B., Mancioppi L., Mouelle R. M., Rebischung F. (2021).Evaluation et limitation des impacts sur la qualite physico-chimique des milieux aquatiques lors des operations de dragage de sediments continentaux : Synthèse des enjeux.Rapport d'etude INERIS-DRC-12-92636-03129B. 34 p.
14. INSEED, (2009).Rapport Data base, commune de Lere, Tchad.
15. INRAE, (2003). Rapport sur la qualite des sols français, INRAE (2013). Recommandations relatives aux travaux et operations impliquant des sediments aquatiques potentiellement contamines - V2 - 06/2013 - Annexes
16. Levêque C., (1971). Prospection hydrobiologique du lac de Lere et des mares avoisinantes. Cah. O.R.S.T.O.M., ser. Hydrobiol., vol. V-2 161-l69

17. Levêque C., (2019).La memoire des fleuves et des rivières. L'histoire des relations entre les hommes et les cours d'eau à travers les siècles. Collection Nature et histoire. 191p.Ed. Ulmer. 2019.
18. Maynard A. J. (1970), Methods in food analysis. Physical, chemical and instrumental methods of analysis.2nd edition. Academic press N.Y., San Francisco. London. 845p.
19. Nadjiam D. (2013). Les ressources en sols du Tchad les actions prioritaires pour une gestion durable. Accra, Ghana. Rapport (2013), 15 p.
20. NASA (2024). http://www.nasa.agroclimatology_data.org(site consulte le 02 août 2024).
21. Passinring K., (2006). Milieux naturels et paysages du bassin – versant des lacs de Lere (MKO, Tchad). Thèse de doctorat, Universite Aix – Marseille I, (2006) 306 p.
22. Passiring K., (2021).Origine structurale et fondements geologiques du decalage geographique des lacs de Lere et Trene : essai de synthèse. Revue des Lettres, Langues et Sciences de l'Homme et de la Societe, 11 (1) 405-417.
23. Saussaye L., Hamdoun H., Boutouil M., Baraud F., Leleyter L., Maherzi W., Le Goff P-A. (2012). Evaluation environnementale de la reutilisation de sediments de dragage en tant que materiau alternatif. XII^{ème} Journee Nationale Genie Côtier – Genie Civil Cherbourg, 12-14 juin 2012. 8 p. DOI:10.5150/jngcgc.2012.119-S.
24. Rodier J., Bazin C., Broutin J. P., Chambon P., Champsaur H., Rodi L. (2005). L'analyse de l'eau, eaux naturelles, eaux residuaires, eau de mer, chimie, physico-chimie,microbiologie, biologie, interpretation des resultats. Ed. Dunod, Paris, 1384 p.
25. Rodier J., Bernard L., Merletet N. C. (2009). L'analyse de l'eau pour statistique. 9eedition Dunon Paris 2009. 5600p.
26. Rofes, G., Trocherie, F., Garat, O., Vallon, M. & Cardinal, H. (1991). Caracterisation des sediments des retenues pour la prevision des risques ecotoxicologiques lies aux vidanges. Revue des sciences de l'eau / Journal ofWater Science, 4(1), 65–82. https://doi.org/10.7202/705090ar
27. Souareba T., Doumnang J. C., Rondouba P., Tarkodjiel M., Mahmout Y, (2024). Evaluation de la contamination par les metaux lourds (Al, Fe, Mn, Ni, Zn, Cr, Cd et Pb) des sediments du bassin du lac Lere, Mayo-Kebbi Ouest, Tchad. Int. J. Biol. Chem. Sci.,18 (2) 723-736. Doi : https://dx.doi.org/10.4314/ijbcs.v18i2.31
28. VMT. Mouyalou, B. Ibouanga, M-D. Mounganga MN. Mefire (2019). Caracterisation physico-chimique des sediments de dragage du port d'Owendo pour leur valorisation. IRSH/CENAREST Libreville, Gabon. 18 p.
29. Wang D., Abriak N. E, Zentar R., Xu W. (2010). Caracterisation physico-chimique d'un sediment portuaire en vue d'une eventuelle valorisation. XI^{ème} Journee Nationale Genie Côtier – Genie Civil Les Sables d'Olonne, 22-25 juin 2010. 8p.