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CHEMICAL QUALITY OF SOIL AND SEDIMENTS OF LAKE TOHO LOCATED IN THE DEPARTMENT OF MONO, SOUTH-WEST OF THE REPUBLIC OF BENIN

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ABSTRACT

In order to assess the pollution status of the sediments in Lake Toho, soil and sediment samples were collected and analyzed using a spectrophotometer. pH values were measured using a HANNA pHmeter probe after sediment treatment. These values show that Lake Toho sediments are basic in the dry season and acidic in the rainy season. Nutrients such as nitrogen and phosphorus are present in high concentrations in the soils surrounding the lake and in the lake sediments. The same applies to heavy metals such as copper, zinc, lead, cadmium, and chromium in the sediments of the lake. These levels of nutrients and metals pose a significant threat to the aquatic organisms present in the lake. It is urgent to establish a management and control system for activities around the lake.

Keywords: Pollution; spectrophotometer; metals; nutrients.

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1. INTRODUCTION

Water is a vital resource, necessary for all living beings, but rare in terms of quality. This resource is unequally distributed throughout the world. It is essential to our health and very important for domestic, agricultural and industrial activities. Benin's wetlands, ecosystems endowed with important resources, are concentrated in the south. According to [1], more than 50% of the country's population (with densities rarely below 150 inhabitants per km²) live in the southern Benin for 10% of the national territory. This situation justifies the fact that the surrounding ecosystems are subject to anthropic pressure that does not guarantee the sustainability of natural resources. [2] shows that in certain ecosystems, chemicals (fertilizers, herbicides, pesticides, etc.) can be the cause of the disappearance of certain animal and/or plant species, leading to an imbalance in the trophic chain (low biodiversity, etc.). Among these chemical pollutants, phosphorus and nitrogen which are nutrients, are responsible for eutrophication, while trace metals (TMEs) are responsible for toxicity. Algal growth depletes water of oxygen, leading fish and other aquatic life to the death [3].

In lakes, massive inputs of nutrients linked to multiple anthropogenic activities cause eutrophication, characterized by the proliferation of water hyacinth [4-5]. Similarly, metals such as copper, zinc, lead and cadmium, brought in by runoff or industrial spills, are a potential danger to human health.

A lake is a body of water completely surrounded by land, usually freshwater: it is a stagnant body of water and does not flow into a river. Lake Toho, the subject of our study, constitutes an environment of biological productivity and potential for fisheries production. This is borne out by the fact that Tossavi reported some twenty species there [6].

In Benin, Lake Toho is one of the most productive bodies of water, where annual fish catches have reached 603.60 metric tons [7]. It should be noted that artisanal fishing and fish farming in pens or ponds, pig farming, aulacodiculture, commerce, crops (sometimes using fertilizers) and handicrafts are activities carried out by the inhabitants in the department. However, hydro-agricultural resources (marshes, lowlands and bodies of water) can be developed for year-round tilapia farming [8].

With a surface area of 9.6 km2 at low water and 15 km2 at rising waters, Lake Toho is located in southwest Benin and averages 7 km in length, 2.5 km in southern width, and around 500 m in northern width [9]. Lake Toho is subject to hydrological dynamics characterized by freshwater inflows from the Mono River (also from the Diko and Akpatohoun creeks) and the Sazoé River during the high-water season [10]. The Kpakohadji channel acts as an outlet and tributary.

Lake Toho undergoes the impact of human activities and inadequate waste management. These activities are of significant economic interest, and are expanding with population growth. The decline in fishery resources was perceived by 91.47% of respondents, compared with 6.20% and 2.33% of respondents who perceived an increase or stability of fishery resources respectively [11]. Fishermen perceive this decline in fishery resources through indicators such as the disappearance of certain fish species, the decrease in the size of fish taken.

2. MATERIALS AND METHODS

2.1. Study area

The study was carried out in the communes of Athiémé, Lokossa, and Houéyogbé, which surround Lake Toho in southern Benin.

Located between the Agamè plateau and the north-western Bopa plateau, Lake Toho extends on average during low-water periods from 6°35' to 6°40' north latitude and from 1°45' to 1°50' east longitude. It is part of the Mono Basin. The latter covers an area of 374 km² and is part of the West complex of wetlands in southern Benin (Ramsar Site, 1017). It has the shape of a crescent oriented South-North.

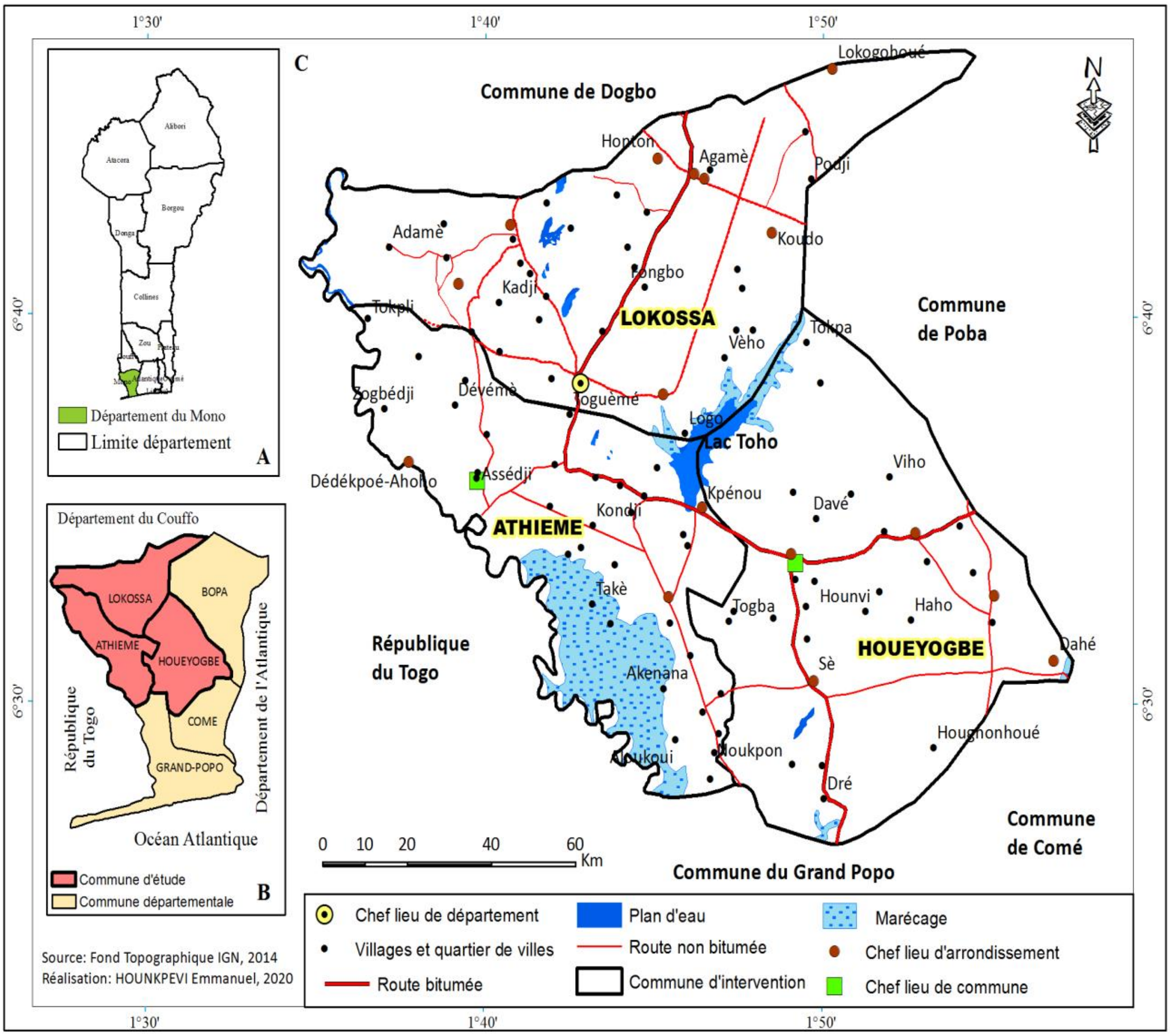


Fig.1. Map of the study area

1.2. Climatic characteristics

Lake Toho has a sub-equatorial climate characterized by two alternating rainy and dry seasons [8].

1.3. Sample collection

Soil and sediment samples were taken from Lake Toho during the dry and rainy seasons at nine (09) points as in Figure 2. Samples were packed in polyethylene bags and taken to the laboratory in two different coolers. In the laboratory, the sediments were dried in a climatic chamber at a temperature of 40°C until the mass was constant. This was followed by clod reduction and sieving of the sample to an average diameter of ≤ 2 mm. These samples were then mineralized for spectrophotometer analysis.

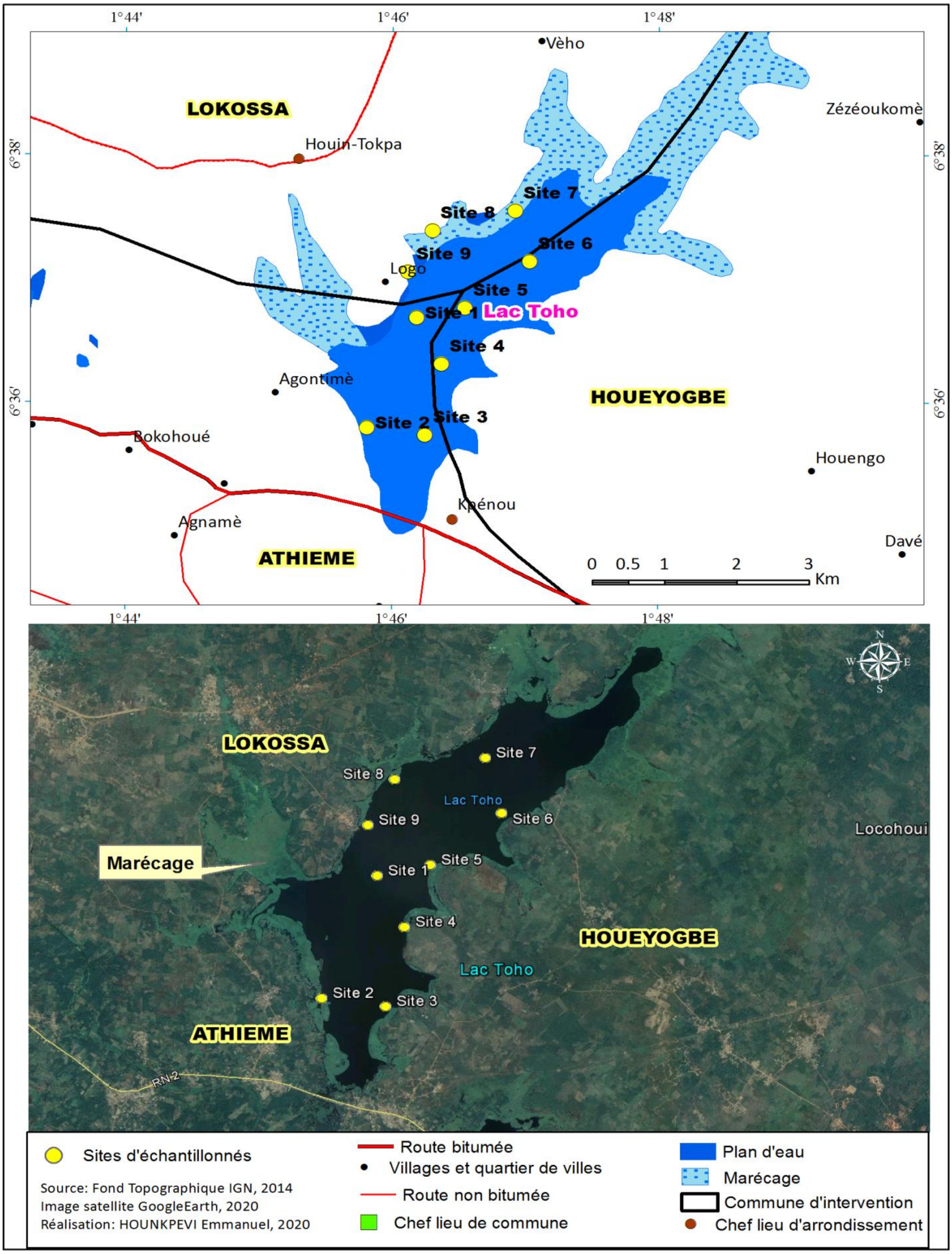


Fig.2. Spatial distribution of sampling sites

1.4. Physico-chemical analyses

TME concentrations (copper, zinc, lead, cadmium, chromium, and nickel) were measured using an atomic absorption spectrophotometer, while total phosphorus and total nitrogen NTK were determined in Lake Toho soils and sediments following mineralization and subsequent determination using a HACH DR3900 spectrophotometer.

2. RESULTS

2.1. Soils

- **Total nitrogen NTK and total phosphorus**

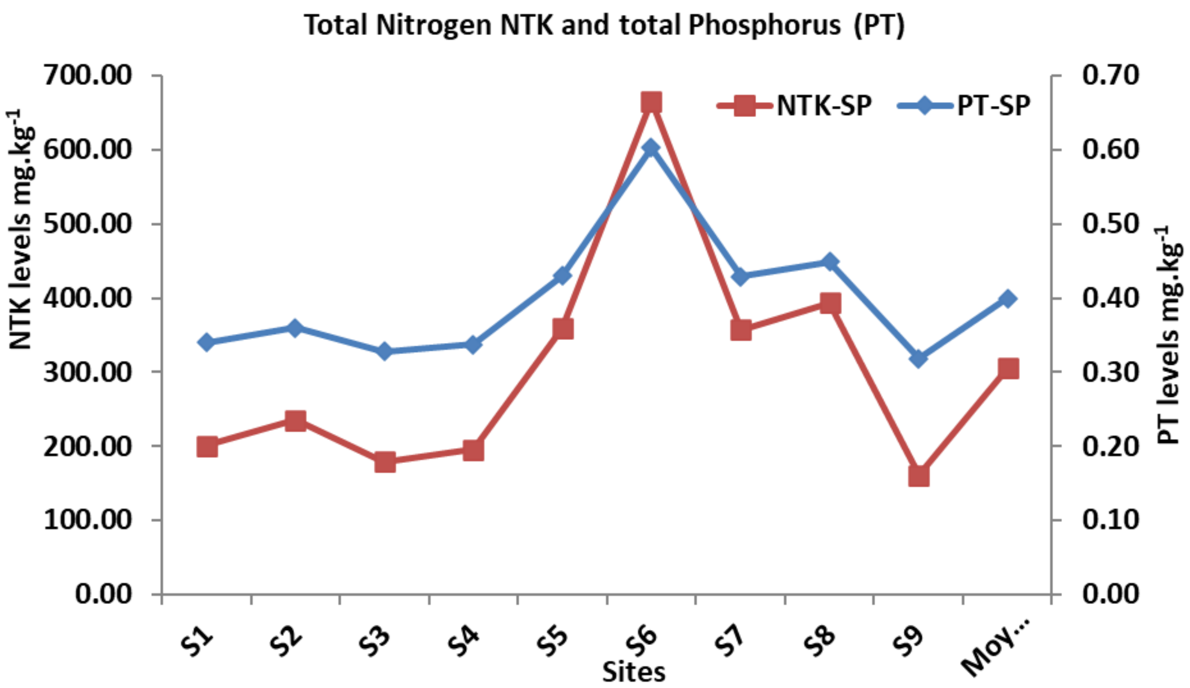


Fig.3. Spatio-temporal variation in total nitrogen and total phosphorus levels in soils around Lake Toho

PSS = Short Dry Season; **GSS** = Long Dry Season; **PSP** = Short Rainy Season

FGSP = Late Rainy Season; **SS**: Dry Season; **SP:** Rainy Season

The total phosphorus levels in the soils (Figure 3) varied from 0.32 to 0.60 mg/kg during the rainy season, with an average of 0.40 mg/kg. The highest value was observed at site 6 and the lowest at site 9.

In the soils, total nitrogen levels (Figure 3) varied from 160.65 to 666.19 mg/kg during the rainy season, with an average of 305.2 mg/kg. The highest value was observed at site 6, and the lowest at site 9.

Total nitrogen and total phosphorus levels in soils show low and high values at the same sites. Moreover, spatial variations in their levels follow the same pattern, as the curves obtained have the same shape. Therefore, it has been deduced that total phosphorus and total nitrogen in soils come from the same source of contamination.

2.2. Sediments

❖ **pH-sediments**

Analysis of figure 4 shows that the pH of Lake Toho sediments varies from 7.56 to 8.58 in the dry season, with an average of 8.01 and from 4.55 to 6.85 in the rainy season, with an average of 6.13 pH units. This reveals that Lake Toho sediments are basic in the dry season and acidic in the rainy season.

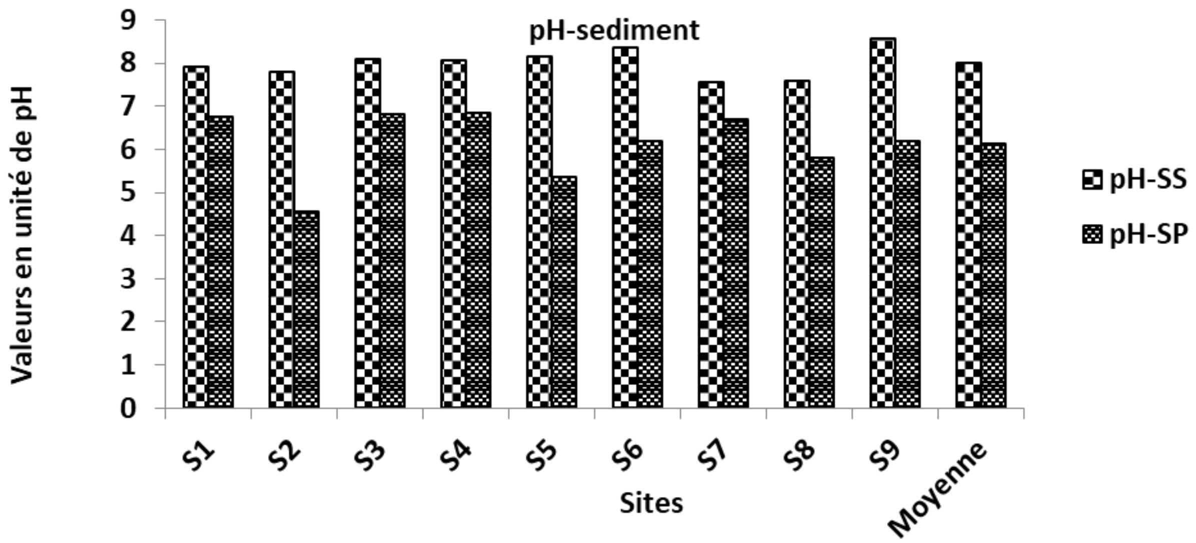


Fig.4. Spatio-temporal variation of pH in Lake Toho sediments

2.2.1. Nutrients

❖ **Total phosphorus and total nitrogen NTK**

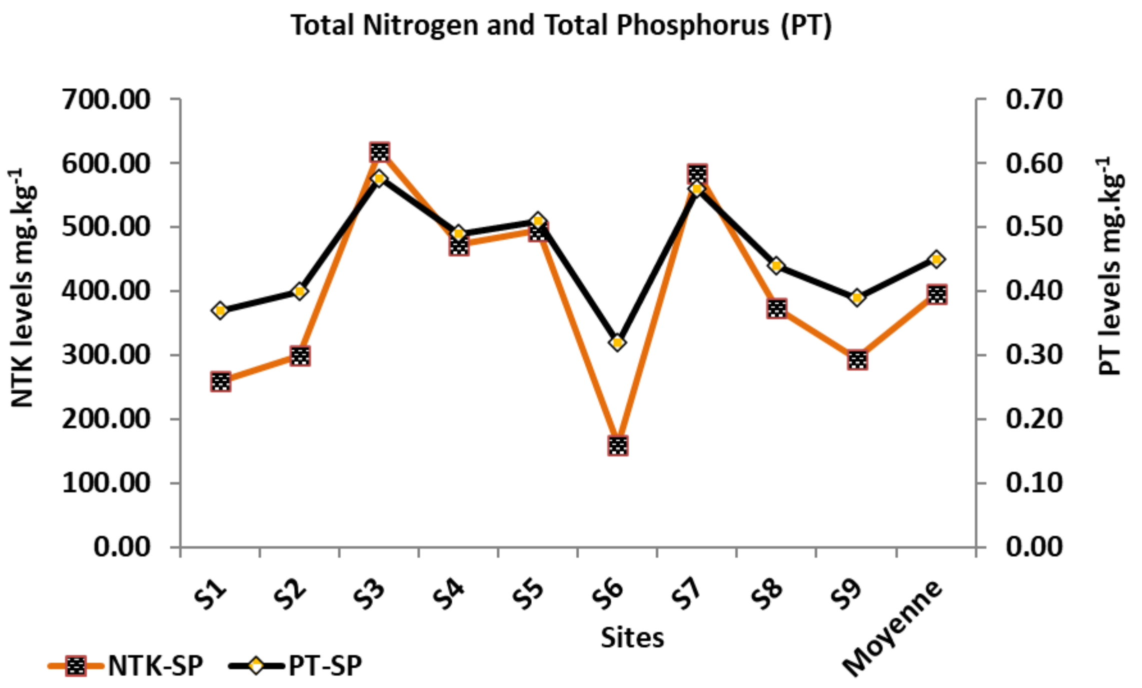


Fig.5. Spatio-temporal variation in total nitrogen and total phosphorus levels in Lake Toho sediments

The analysis of Figure 5 shows that NTK is highly concentrated in sediments during the rainy season. Values ranged from 160.65 to 619.10 mg/kg, with an average of 395.52 mg/kg.

Total phosphorus in sediments throughout the season ranged from 0.32 to 0.58 mg/kg, with an average of 0.45 mg/kg in the rainy season (Fig. 5). The highest values were found at site 3 (Kpinnou) and the lowest at site 6.

The highest NTK and total phosphorus values are found at site 3, and the lowest at site 6. Furthermore, the spatial variation curve for nitrogen shows the same pattern as that for total phosphorus (Figure 5). We also deduce that total phosphorus and total nitrogen in the sediments come from the same source of contamination.

2.2.2. Metallic Trace Elements (MTE)

- **Lead (Pb) and Cadmium (Cd)**

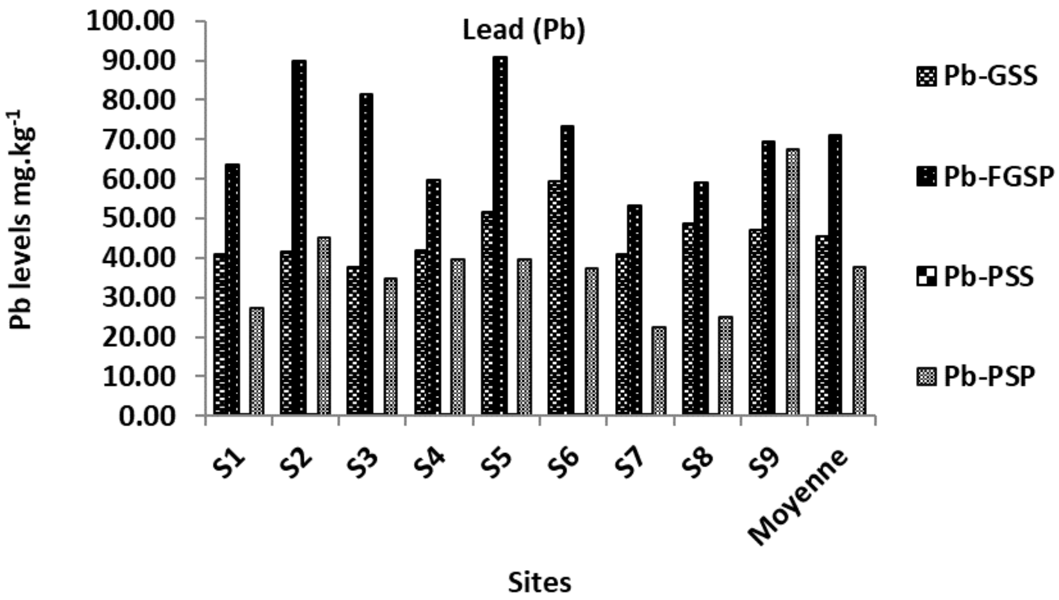


Fig.6. Spatio-temporal variation in lead levels in Lake Toho sediments

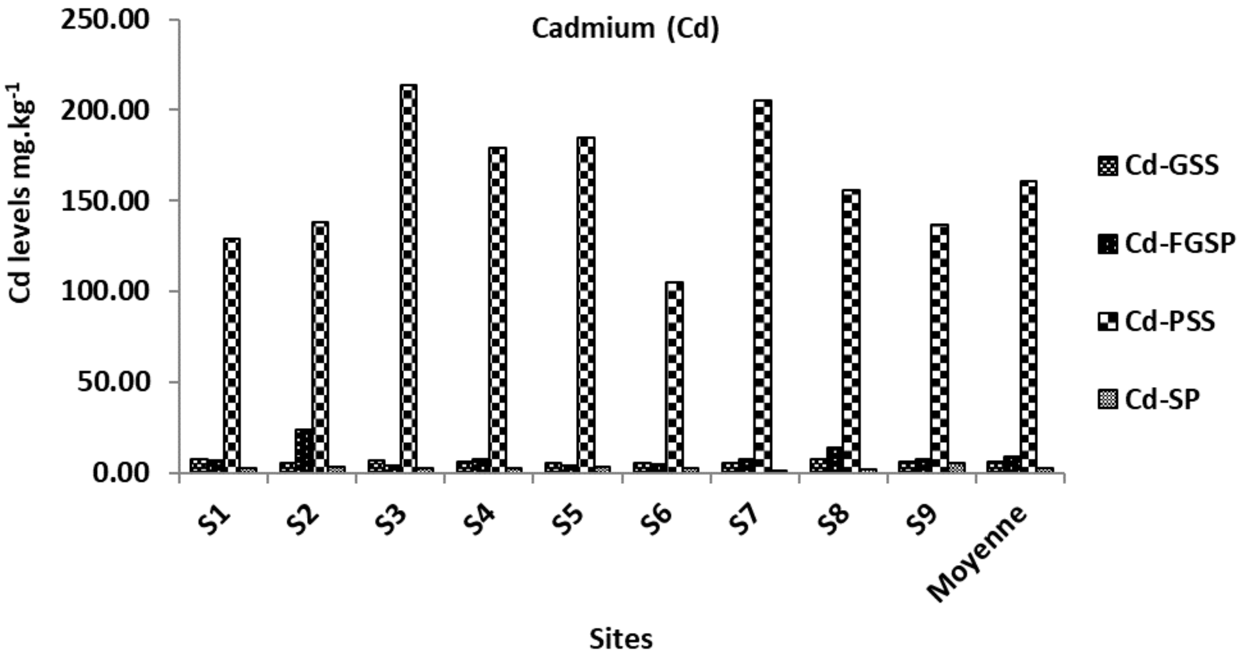
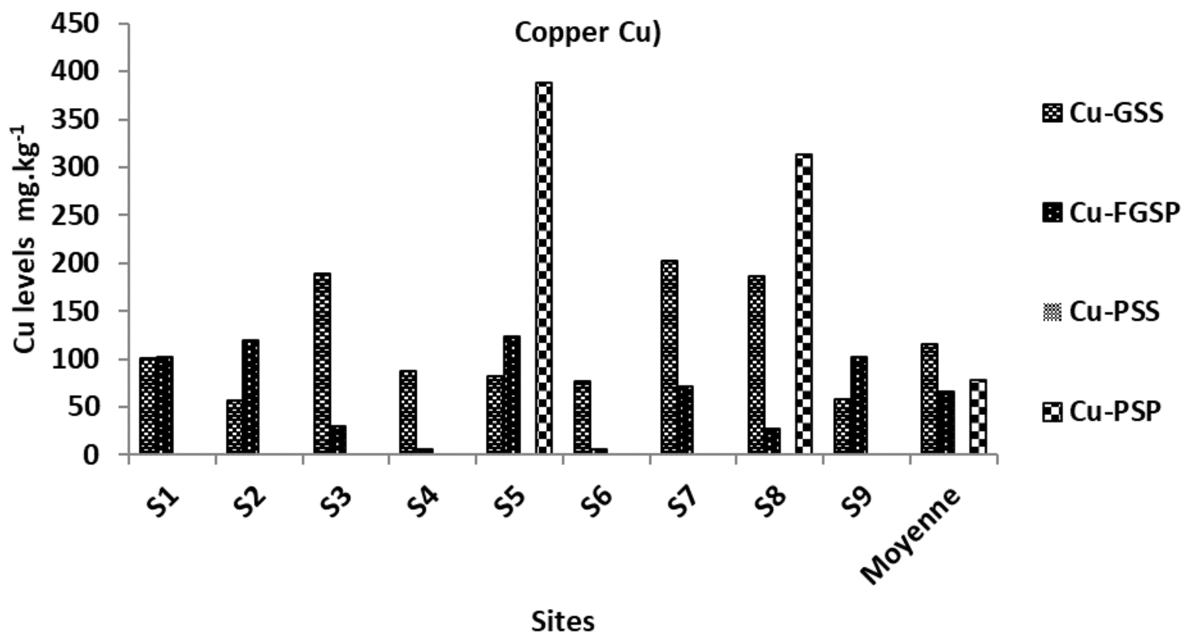


Fig.7. Spatio-temporal variation in cadmium levels in Lake Toho sediments

Analysis of Figures 6 and 7 shows that lead and cadmium are permanent in Lake Toho sediments. Lead is predominantly present during three seasons, while cadmium is present during one season. Lead is more concentrated in sediments during the main rainy season, with the highest value (90.93 mg/kg) obtained at site 5. As for cadmium, it is more concentrated during the short dry season, with the highest average value obtained at site 3 (213.84 mg/kg). This may be linked to the evapotranspiration effect.

The analysis also reveals that, starting with the different lead levels, all the values recorded at the end of the long rainy season and those of the short rainy season and their averages exceed those obtained during the long and short dry seasons respectively. For cadmium, the average level (8.83 mg/kg) obtained at the end of the long rainy season exceeds that obtained during the long dry season (6.31 mg/kg). This suggests that runoff is a source of lead and cadmium in Lake Toho sediments.



❖ **Copper (Cu) and Zinc (Zn)**

Fig.8. Spatio-temporal variation in copper levels in Lake Toho sediments

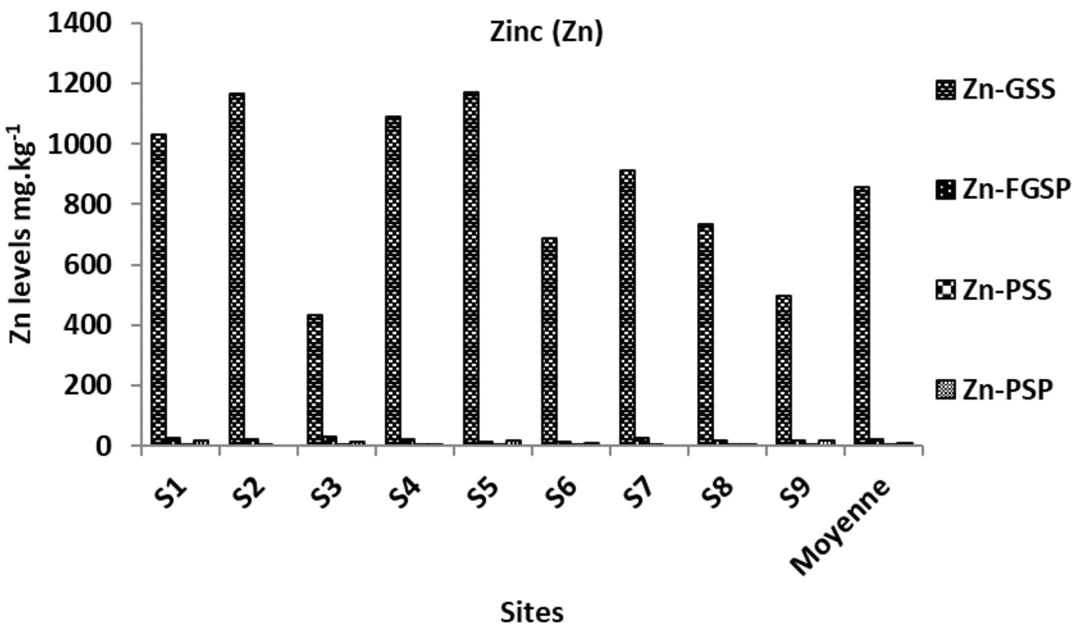


Fig.9. Spatial and temporal variations in zinc content in Lake Toho sediments

Analysis of Figures 8 and 9 shows that copper and zinc concentrations in lake sediments are high respectively during the short rainy season and the long dry season (202.55 mg/kg for copper at site 7 and 1168 mg/kg for zinc at site 5, respectively). During the short rainy season, copper was absent from seven (07) sites. Zinc was absent at two (02) sites during the same season. The respective averages obtained during the rainy seasons exceed those recorded for each of these metals during the short dry season. It can be seen that rainwater and various runoff discharges are responsible for the inputs of dissolved copper and zinc, which seep into the sediments of Lake Toho.

❖ **Chromium**

Figure 10 reveals that chromium is more concentrated in sediments during the rainy season than in the dry season. Chromium is permanently present in both seasons, but at very low levels at all sites during the dry season. The highest value (106.48 mg/kg) is found at site 6. Similarly, the high concentrations observed during the rainy season indicate pollution mainly caused by runoff.

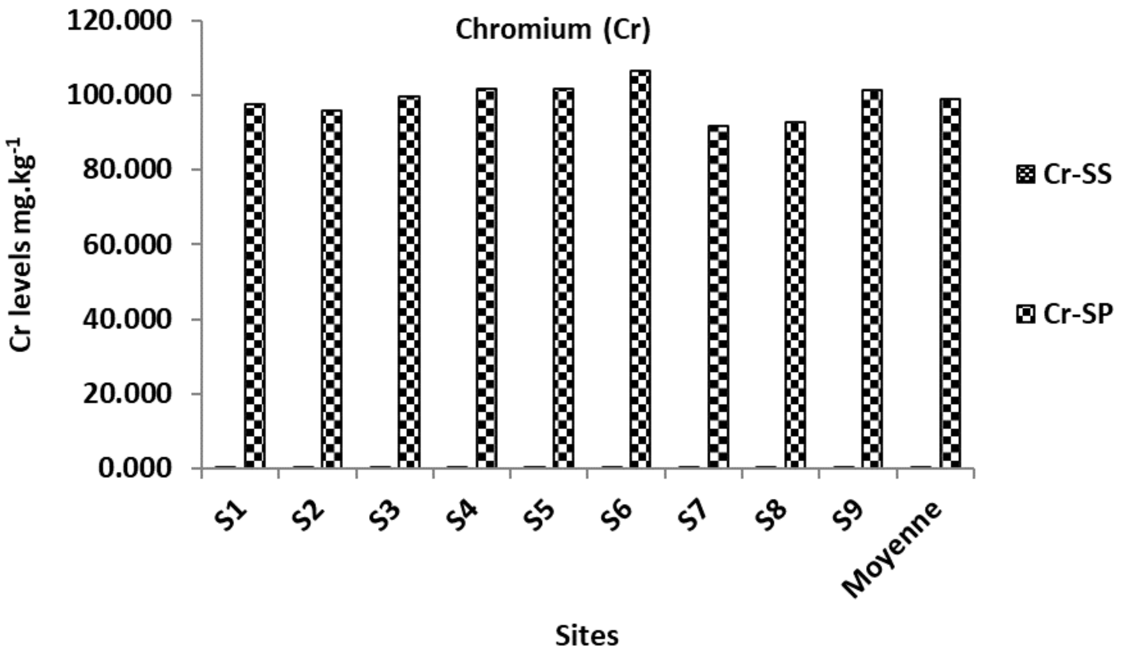


Fig.10. Spatio-temporal variation in chromium levels in Lake Toho sediments

❖ **Nickel (Ni)**

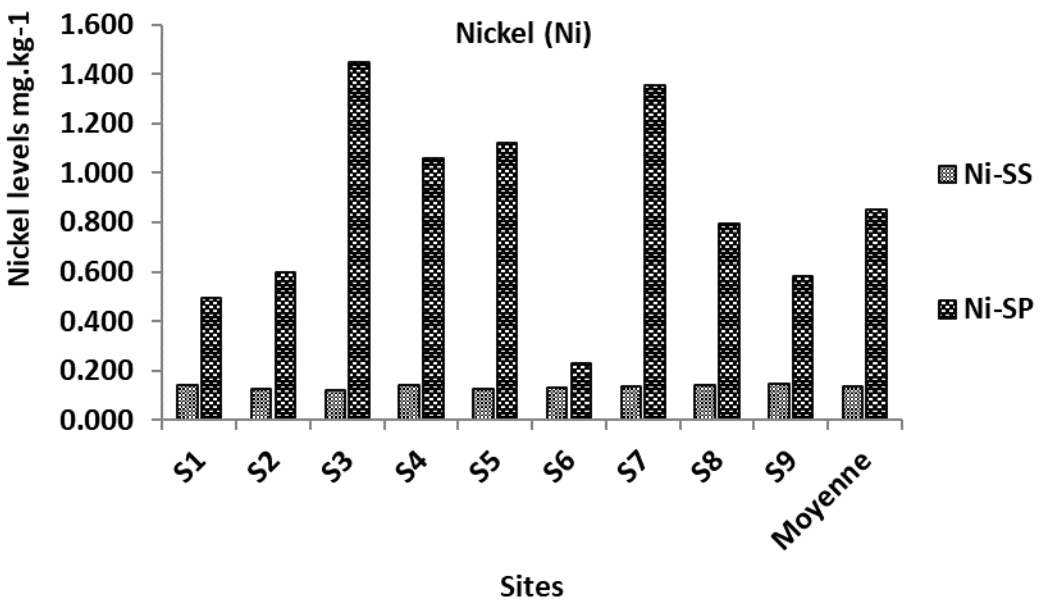


Fig.11. Spatial and temporal variations in nickel levels in Lake Toho sediments

Figure 11 shows the permanent presence of nickel during the dry and rainy seasons. Analysis of the curve reveals more concentration of nickel in sediments during the rainy season.

3. DISCUSSION

The study of chemical pollution through the chemical quality of Lake Toho soils and sediments takes into account nitrogen pollution, phosphorus pollution, and trace metal elements.

Sediment pH shows that Lake Toho sediment is basic in the dry season and acidic in the rainy season. The pH therefore decreases from dry to wet season. The redox and pH conditions at the water-sediment interface are thus modified [12]. pH and redox conditions have a strong influence on the ability of sediments to trap or salt out phosphorus and metallic elements [12-13]. A drop in pH contributes to the passage of metals into the dissolved phase, and thereby increasing their bioavailability. The results of nutrient analyses reveal very high average values, particularly for total nitrogen NTK in lake sediments (395.52 mg/kg). The highest value of 619.1 mg/kg was obtained at Kpinnou. The results also reveal a very high mean value for NTK in soils sampled from the crop fields around Lake Toho (305.21 mg/kg), with the highest value of 666.19 mg/kg obtained at site 6. The average value of total phosphorus obtained is of 0.45 mg/kg in sediments and 0.4 mg/kg in soils. The study shows that lake sediments and the soils surrounding them are rich in nitrogen and phosphorus. This confirms that the nutrients brought into the lake by runoff come from crop fields (an exogenous source of pollution). According to [13], endogenous sources of nutrients come mainly from sediment release. [14] follows the same logic, showing that the sources of phosphorus in the Porto-Novo lagoon are of two types: diffuse inputs (mainly runoff on cultivated soils) and point inputs (industrial or domestic discharges). This shows that the soils around Lake Toho and its sediments are respectively exogenous and endogenous sources of nutrients that feed the water column. The same trends for total nitrogen and total phosphorus in the cultivable soils around the lake and lake sediments reveal that these nutrients come from an anthropogenic source (reinforced by the use of chemical fertilizers, as the lake is located in a rural setting dominated by agricultural activities). It should be noted that Kpinnou (site 3) is a high-risk site for fish farming due to its high levels of nitrogen and phosphorus in the sediments, which would deplete the aquatic environment of oxygen and contribute to the mass death of fish in May 2018.

The results of the trace metal analyses, starting with the various lead levels, reveal that all the recorded values at the end of the long rainy season and the short rainy season, as well as their averages, exceed those respectively obtained during the long and short dry seasons. This means that runoff is a source of lead presence in Lake Toho sediments. We also note that, according to the succession of seasons, lead concentrations increase from the short rainy season to the long rainy season. As for cadmium, we deduce beforehand that run-off water is a source of dissolved metal, for the obtained average (8.83 mg/kg) during the end of the long rainy season exceeds that obtained during the long dry season (6.31 mg/kg). The average values of copper and zinc elements (respectively 65.91 and 77.94 mg/kg for copper; 20.62 and 9.01 mg/kg for zinc) recorded during the long and short rainy seasons far exceed those obtained during the short dry season for each of these metals. All the above metals are therefore supplied by rainwater runoff. According to [15], an analysis of chemical fertilizers shows a content of 6.25 mg/kg for zinc and 2.95 mg/kg for copper. It appears that the high TME values in the sediments are also due to the use of chemical fertilizers and pesticides, as the lake is located in a rural area dominated by agricultural activities.

The overall analysis of the results of the determination of TMEs in sediments taken from Lake Toho (67.5 mg/kg for lead; 19.19 mg/kg for zinc, 5.5 mg/kg for cadmium and 388.06 mg/kg for copper) shows that the values obtained during the short rainy season are respectively lower (except lead content) than those obtained by [16] in lake sediments during the same season and close to the period of fish carnage taking place in May 2018: 60.75 mg/kg for lead; 340 mg/kg for zinc, 7 mg/kg for cadmium and 2100 mg/kg of copper. In comparison with the results found during the main rainy season by other authors, the values obtained in the sediments of Lake Toho (90.93 mg/kg for lead; 30 mg/kg for zinc, 23.48 mg/kg for cadmium and 123.26 mg/kg copper) differ from those found by [17] on Lake Ahémé: 26.25 mg/kg for lead; 35 mg/kg for zinc and by [3] in the Porto-Novo lagoon: 105 mg/kg lead, around 10 mg/kg cadmium. In the dry season, the highest values recorded (59.48 mg/kg for lead; 1168 mg/kg for zinc, 7.71 mg/kg for cadmium, and 202.55 mg/kg for copper) far exceed those obtained by [17] on Lake Ahémé: 25 mg/kg for lead; 170 mg/kg for zinc and by [3] in the Porto-Novo lagoon: 5.65 mg/kg for lead, around 0.3 mg/kg for cadmium. In the case of chromium, all the levels recorded are low in the dry season compared with those obtained during the rainy season. It can therefore be deduced that the high concentrations observed during the rainy season are indicative of pollution resulting from anthropogenic activities, with run-off water and sewage as main sources. Nickel is permanently present but in low concentrations in lake sediments during both the wet and dry seasons. We can also deduce that this metal is brought in by run-off water, as the values recorded in the rainy season and the average far exceed those obtained in the dry season.

The Canadian Council of Ministers of the Environment, through the Canadian Environmental Quality Guidelines for the Protection of Aquatic Life, which are based on the work of various researchers, is proof of the precautions to be taken for better protection of aquatic ecosystems. The average values obtained in this study for cadmium (including all sites), lead, copper (excluding the short dry season), zinc (long dry season only) and chromium (excluding the dry season) exceed the threshold values (25 mg/Kg for lead and chromium; 80 mg/Kg for zinc, 0.33 mg/Kg for cadmium and 22 mg/kg of copper) set in these recommendations [18]. The numerous harmful effects of metals on aquatic organisms are well documented. One of these is the toxicity of the aquatic environment through the mechanism or phenomenon of sediment release. In fact, reduced benthic invertebrate abundance and fertilization, increased mortality, lethality, behavioral changes, and abnormal development in the early life stages of benthic organisms are the biological adverse effects listed for these various metals [19]. In neutral or basic waters, metals previously dissolved at an acidic pH precipitate and accumulate mainly in the solid phase (sediments). They are deposited on bottom substrates and eventually incorporated into sediments. As a result, sediments can become an endogenous source of pollution for water bodies through the phenomenon of release (Gbaguidi, 2020).

The high levels of metals in the sediments of Lake Toho are thought to contribute to their toxicity and to have contributed to the fish carnage that occurred in May 2018 at Kpinnou in the commune of Athiémé and August 2021.

4. CONCLUSION

Analyses carried out over several seasons reveal a high level of nitrogen and phosphorus pollution due to human activities around the lake. We also deduce a change in redox and pH conditions likely to promote the salting-out of phosphorus and metals into the lake's water column et des The variation curves for total phosphorus and total nitrogen NTK in soils and sediments show the same pattern, indicating a rational input of these nutrients from human activities based mainly on agricultural work using nitrogen and phosphorus products. These nutrients in the sediments contaminate the aquatic environment, depleting it of oxygen and creating life-threatening conditions for fish, leading to their mass mortality. Lake Toho sediments are also subject to chemical pollution due to high levels of TMEs such as copper, zinc, lead, cadmium, and chromium. Run-off water is an exogenous source of nutrient and TME contamination of Lake Toho sediments, which are thought to originate from agricultural fields through the use of NPK fertilizers rich in nitrogen, phosphorus, and TMEs, not to mention other discharge channels. It should be noted that Kpinnou (site 3) is a high-risk site for fish farming due to its high levels of nitrogen and phosphorus in the sediments, which would deplete the aquatic site of oxygen and contribute to the mass death of fish in May 2018. About metals, the high levels obtained in lake sediments represent a potential threat to their toxicity and would also participate in the fish carnage that occurred in May 2018 at Kpinnou in the commune of Athiémé.

5. REFERENCE

[1] da Matha-Sant'anna M., (2001). Régime d'occupation des terres, statut des aires protégées, modes de gestion et d'aménagement, activités humaines et habitats humains. PAZH. Cotonou-Bénin. 35 pp.

[2] Gold C., (2002). Etude des effets de la pollution métallique (Cd/Zn) sur la structure des communautés de diatomées périphytiques des cours d'eau. Approches expérimentales in situ et en laboratoire. Thèse de Doctorat, Université Bordeaux I, 175 pp.

[3] Chouti W., (2011). Etude de la pollution chimique d'une lagune tropicale (eaux, sédiments, poissons) : Cas de la lagune de Porto-Novo (sud Bénin). Thèse de doctorat à l'Université d'Abomey-Calavi, 100p + Annexes.

[4] Ogutu O. R, Hecky RE, Cohen SA, Kauf L. 1997. Human Impacts on the African Great Lakes. Environmental Biology of Fishes, 50: 117–137.

[5] Mama D., 2010. Méthodologie et résultats du diagnostic de l'eutrophisation du lac Nokoué (Benin). Thèse de doctorat, Université de Limoges ; 157p.

[6] Tossavi CE, 2012, Evolution de la biodiversité et de l'exploitation des poissons du lac Toho (Sud Bénin) : Implications pour la gestion durable des ressources halieutiques. Mémoire de Master en Hydrobiologie Appliquée, Faculté des Sciences et Techniques/UAC, 118p.

[7] Robin L Welcomme, 1979. Fisheries Ecology of Floodplain Rivers. Longman, p.325, ISBN 0-582-46310-6.

[8] Evélyne KPLE, 2008, Contribution à l'étude de la pollution organique et azotée des eaux du lac Toho dans le département du Mono. Rapport de fin de formation pour l'obtention d'une Licence Professionnelle (LP) à l'université d'Abomey-Calavi/Bénin, p84.

[9] Ahouansou M. S., 2003, Etude de l'écologie et de la production halieutique du lac Toho au Bénin. Mémoire de DESS, Faculté des Sciences Agronomiques, Université d'Abomey-Calavi (FSA/UAC). 83p.

[10] Adite A., 2002, Diversity and management of mangrove fishes in the Benin coastal zone. Research Technical Report. International Foundation for Science-IFS, 26.

[11] Codjo V et *al.*, 2018, Baisse des ressources halieutiques du lac Toho au sud du Bénin : perceptions des pêcheurs et efficacité des pratiques de Gestion et stratégies d'adaptation. TROPICULTURA, 36, 4, 713-721

[12] Ghassen I, Aurélie L. H, Clara O. 2014. Etude diagnostique du lac des Rapides. Organisme de bassins versants Duplessis - 719 boul. Laure, Sept-Îles (QC) G4R 1Y2

[13] Daouda MAMA. (2011), Caractérisation physico-chimique et évaluation du risque d'eutrophisation du lac Nokoué (Bénin), Int. J. Biol. Chem. Sci. 5(5): 2076-2093.

[14] Chouti W K, Atchichoe W, Tometin L, Daouda M., J. Appl. Biosci. 2017. 114: 11276-11288, ISSN 1997-5902. https://dx.doi.org/10.4314/jab.v114i1.1

[15] GBAGUIDI Jean, 2018, Contribution à la protection contre des pollutions chimiques d'un système lentique en région tropicale: le lac Toho au sud-Bénin, Afrique de l'ouest. Mémoire de fin de formation réalisé et soutenu pour l'obtention du diplôme de Master Professionnel en Hydrologie, 95 p.

[16] Gbaguidi J G, Topanou, Fatombi J, Moyo E A, Mama D, Aminou T. Journal of Bioscience and Applied Research, 2020, Vol.6, No. 1, P.8 -19.

[17] F Dimon et *al.*, 2014, Caractérisation physico-chimique du lac Ahémé (Sud Bénin) et mise en relief de la pollution des sédiments par le plomb, le zinc et l'arsenic. J. Soc. Ouest-Afr. Chim. (2014), 037: 36- 42.

[18] Critères pour l'évaluation de la qualité des sédiments d'eau douce. 2007. Environnement Canada et Ministère du Développement Durable, de l'Environnement et des Parcs du Québec.

Environnement Canada. 1997. Canadian sediment quality guidelines for cadmium : Supporting document. Service de la conservation de l'environnement, Direction générale de la science des écosystèmes, Direction de la qualité de l'environnement et de la politique scientifique, Division des recommandations et des normes, Ottawa.