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Anthropogenic activities and contamination of Taabo Lake sediments by trace metals (cadmium, mercury, lead and chromium)

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ABSTRACT

Pollution by trace metals (TME) is a current problem that concerns the scientific community concerned with maintaining the environment at a level of quality conducive to human health and well-being. The objective of this study is to evaluate the level of contamination of the sediments of Taabo Lake by cadmium, mercury, lead and chromium. To do this, 15 sediment samples were collected in three (3) sampling campaigns, from five (5) stations. Analyses by the Varian flame atomic absorption spectrometric (AAS) method for chromium, lead and cadmium and, the cold vapor atomic absorption spectrometric (CV-AAS) method for mercury focused on the fine fractions of the sediments ($\varphi < 63$ µm). Geoaccumulation index (Igeo) and Contamination factor (FC) were determined for establishing the level of contamination of sediments by metallic trace.The results show that the concentrations of cadmium (2.494 ppm), mercury (0.685 ppm) and lead (17.850 ppm) in the sediments of Taabo Lake are higher than in the earth's crust. Chromium, on the other hand, at 6.980 ppm, is lower than the earth's crust. The geoaccumulation index (Igeo) and the contamination factor (CF) revealed sediments highly contaminated by cadmium and mercury. Lead contamination of sediments is said to be moderate. However, low or no chromium contamination of sediments was found.

Keywords : Taabo Lake, Sediments, ETM, Pollution indexes.

INTRODUCTION

Metal pollution is a significant hazard in the world today. It is a current problem that concerns scientists concerned with maintaining the environment at a high level of quality (Naili *et al.*, 2016; Dahri *et al.*, 2018). This is because trace metal elements (TME) can be hazardous to human health and other organisms when present in the environment at high concentrations (Irie, 2017). Furthermore, TME represents only 0.6% of the total chemical elements in the Earth's crust. However, their effects on ecosystems are often devastating (Kabata-Pandias and Mukherjee, 2007; Soro *et al.*, 2009). Indeed, on a global scale, anthropogenic emissions of most TME exceed natural fluxes in the environment (Smatti-Hamza *et al.*, 2019). In aquatic ecosystems, they are transferred to biota, including fish and, ultimately, humans (Kouamé *et al.*, 2016). To this end, the assessment of the level of contamination of aquatic ecosystems by trace elements, toxic at high concentrations, can be evaluated in water, aquatic organisms such as fish

(Kouamenan *et al.*, 2020), crabs (Kouamé *et al.*, 2019) but especially in sediments (Afri-Mehennaoui *et al.*, 2009; Sahli *et al.*, 2014; Bhaskar *et al.*, 2016; Djeddi *et al.*, 2018 and Keddari *et al.*, 2019a). Sediments are a sink for pollutants and memory of aquatic environments. Unlike organic pollutants, TMEs cannot be biologically and chemically degraded (Senou *et al.*, 2012). They persist in the background and have toxic effects on different living organisms and their discharge environment (Storelli *et al.*, 2005). They can accumulate in the flesh of fish consumed by humans (Rohasliney *et al.*, 2014; Makedonski *et al.*, 2015; Nadzifah *et al.*, 2017; Merhaby, 2018 and Diop *et al.*, 2019). Therefore, the objective of this study is to assess the level of contamination of Taabo Lake sediments by trace metal elements (Cd, Hg, Pb, and Cr).

1- MATERIALS AND METHODS

1.1- Presentation of the study area

The Taabo hydroelectric scheme is located on the Bandama River about 110 km downstream from white Bandama and red Bandama (Marahoue) and about 120 km downstream from the Kossou. The watershed of this river, from upstream to Taabo, is located in the middle of the basement and belongs to the old Precambrian shield of West Africa (Avenard, 1971). The watershed area drained by the Taabo dam is 58,700 km2 (Kaiser Engineers and Constructions, 1980). Taabo Lake covers an area of 69 km² at the normal impoundment elevation. It is located between 5°07' and 5°33' W longitude, 6°25' and 6°56' N latitude and has an elongated NW-SE shape with a single eastern diverticulum (Figure 1). This dam has been in operation since January 18, 1979 (Kaiser Engineers and Constructions, 1980). Its head varies between 52 and 59 m. The volume at the normal flood level (124 m) is 625x106 m^3. This is an area of intense agricultural activity, particularly cocoa production, which requires the unbridled use of fertilizers and pesticides in the treatment of plantations, with considerable impacts on this lake, as shown in the figure below.

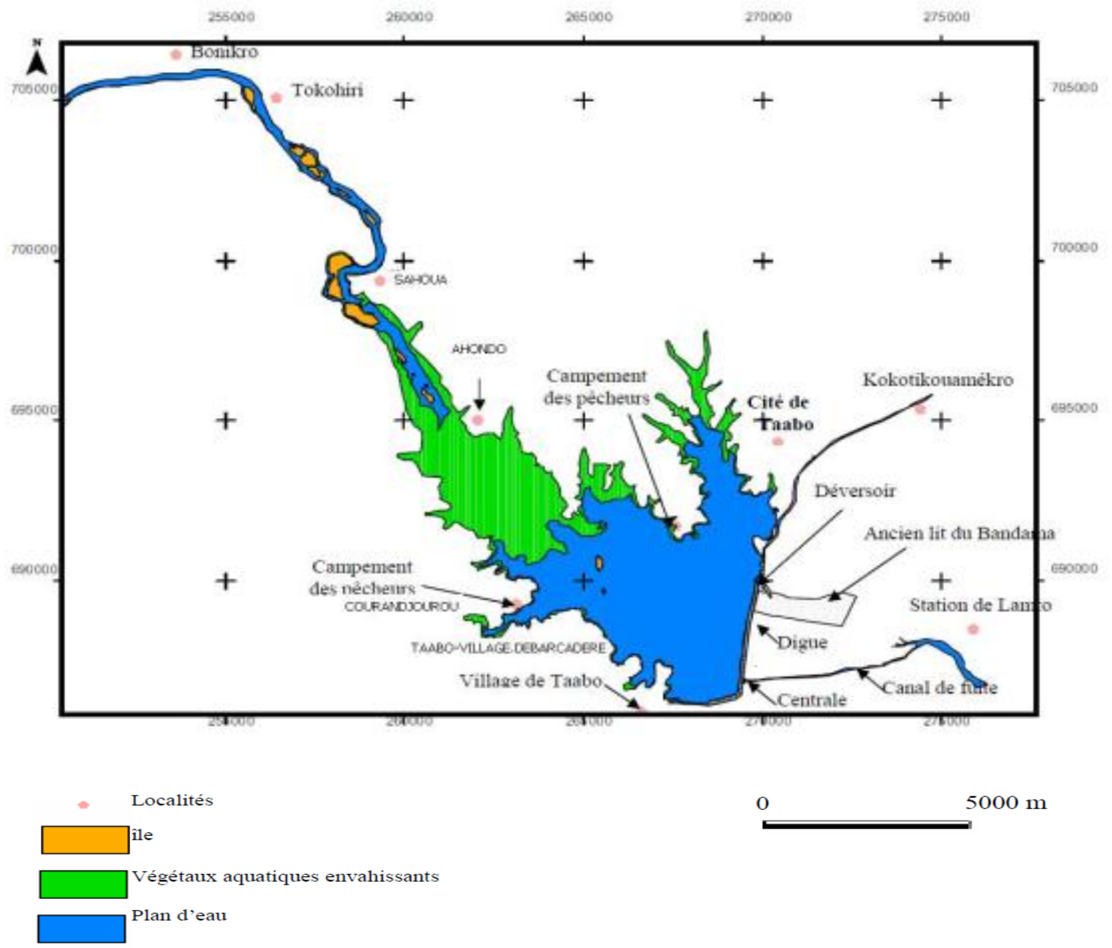

Figure 1: Map of Taabo Lake (Groga, 2012)

Sediment Sampling

The characteristics and geographic coordinates of the sediment sampling stations at Taabo Lake are noted as follows
- Station 1 (S1): 06o15.133' North and 005o04.719' West, this site includes banana plantations and a SODECI establishment;
- Station 2 (S2): 06o14.914' North and 005o04.952' West, this sampling station is dominated by agricultural activities;

- Station 3 (S3): 06o15.047' North and 005o05.842' West, this site includes fish cage breeding activities by the SEDP;
- Station 4 (S4): 06o14.765' North and 005o07.118' West, are integrated in the perimeter of this station of sampling of household activities of the village Kokorakro;
- Station 5 (S5): 06o14.201' North and 005o07.163' West, is noted an island, the bed of the river that feeds the Taabo dam (Figure 2).

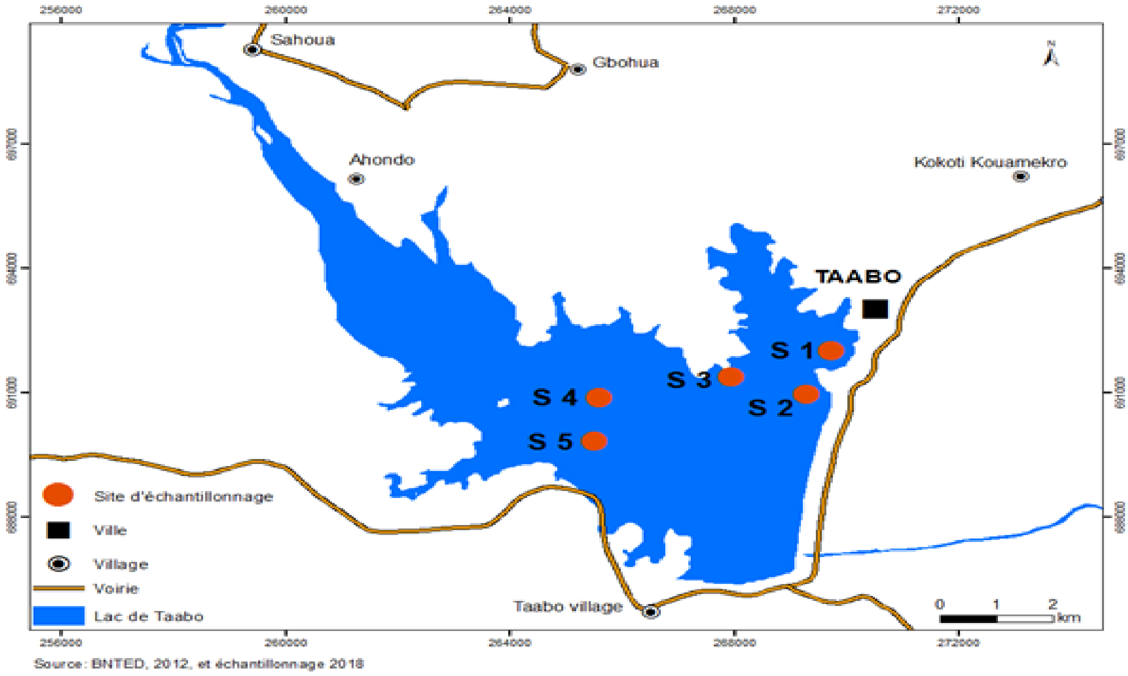

Figure 2: Taabo Lake sediment sampling sites

Sediment sampling, carried out using a Van Veen grab sampler, took place from August 2018 to June 2019 during seasonal campaigns. Indeed, three (3) sampling campaigns held in October (flood season), March (dry season) and June (rainy season) from the five (5) sampling stations (Figure 2) collected a total of 15 sediment samples.
After sampling, the sediments were kept in plastic bags to prevent contamination, placed in a cooler containing carbo-ice and kept at 4°C for transport to the Oceanological Research Center (ORC) in Abidjan for processing and analysis.

1.2- Treatment of sediments and trace element analysis

- Physical Pre-treatment of raw sediments

The sediments consisting of sands and muds were dried at 40°C in an oven and then sieved after homogenization by grinding with an agate mortar and pestle. This operation separates the fine fraction (< 63 µm) from the coarse fraction. This fine fraction was retained for the various analyses. Consequently, it has more affinity for TME.

- Chemical pretreatment of the fine fraction

The digestion of 0.5g of the fraction intended for analysis was done hot by a mixture of 4 mL of aqua regia (hydrochloric acid (37%), nitric acid (65%), 3/1 (v/v)) and 3 mL of hydrofluoric acid in Teflon vials. After a few resting times in room air, the residue is taken up in a boric acid solution (2.7g in 20 mL of bi-distilled water). Finally, biodistilled water was added to the solution to bring the final volume to 50 mL. To ensure the accuracy of the results, blanks and a BCR-320 certified sediment were processed. The blanks correspond to acid attacks without sediment. They allow verifying the absence of contamination related to the material used. The certified sediment underwent the same treatment as the sediment samples. Therefore, it will enable evaluating the accuracy of the measurements.

- Determination of metallic trace elements

The Varian flame atomic absorption spectrometry (AAS) method was used for the determination of chromium, lead and cadmium and the cold vapor atomic absorption spectrometry (CV-AAS) method for the determination of mercury.

Varian flame atomic absorption spectrometry (AAS) is used to determine trace metal elements, preferably in solution. Each atom to be determined has a beam of known intensity and wavelength based on the absorption of photons by this atom in the ground state. The principle of AAS is to vaporize the liquid sample and heat it with a flame or an oven. Radiation defined by a frequency specific to the analyzed element is sent. The absorption of the radiation by the atoms present is proportional to the concentration of the element considered. As for the determination by CV-AAS, a Perkin type atomic absorption spectrometer equipped with a deuterium lamp that corrects the background noise was used. Mercury measurements are performed in triplicate at 253.9 nm wavelength. The results are expressed as mg/kg of the trace element in the sample according to the following equation:

$$C = (C1 * V)/(m * F)$$

With:
C, final sample concentration in ppm;
C1, the concentration of the sample solution in mg/L;
m, sample mass (g) and F, dilution factor of the tested solution.

1.3- Level of contamination of sediments by trace metals

- Geoaccumulation index (Igeo)

It is a criterion for evaluating the intensity of metallic contamination (Müller, 1969). This index of empirical character compares a given concentration versus a value considered as geochemical background. Coefficient 1.5 (correction factor) accounts for variations in background levels that lithology effects may cause. The Igeox is calculated according to the following formula:

$$Igeo_x = log_2(\frac{C_x}{1,5B_x})$$

With:
Cx : measured concentration for a trace element x ;
Bgx: geochemical background for a trace element x.
Müller (1981) defined a scale with six classes of geoaccumulation index:
- Igeo ≤ 0: No pollution;
- 0 < Igeo < 1: Unpolluted to moderately polluted;
- 1 < Igeo < 2: Moderately polluted;
- 2 < Igeo < 3: Moderately polluted to heavily polluted;
- 3 < Igeo < 4: Heavily polluted;
- 4 < Igeo < 5: Heavily polluted to extremely polluted and,
- Igeo > 5, Extremely polluted.

To calculate this index, we used the geochemical background levels of the earth's crust as background.

Trace metallic elements	**Cadmium (Cd)**	**Mercury (Hg)**	**Lead (Pb)**	**Chromium (Cr)**
Continental crust (UCC) (ppm)	0.10	0.056	17	35

- Contamination factor (FC)

The Igeo index is used to establish a classification of sediments according to the concentrations of metallic contaminants. Nevertheless, the coefficient 1.5, which, a priori, takes into account the heterogeneity of the sediment, does not always represent reality. Indeed, the TME is mainly associated with sediment particles (clays, carbonates, iron oxides and hydroxides, organic matter...). Therefore, it would be necessary to express the concentrations of TME as a function of a parameter related to the nature of the sediment. This normalization which consists in expressing the ratio of the content of a given substance compared to that of the normalizing factor makes it possible to define the contamination factor "FC" of a given trace element in the sediment. The following formula expresses this contamination factor:

$$CF = \frac{Cx}{Bgx}$$

With:
- ✓ Cx : measured concentration for an element x ;
- ✓ Bgx: geochemical background for an element x.

The contamination classes defined for FC are, according to Rubio *et al.* (2000):
- CF < 1, absent to low contamination;
- 1 ≤ CF < 3, moderate contamination;

- $3 \leq CF < 6$, considerable contamination and,
- $6 \leq CF$, very heavy contamination.

1.4- Statistical data processing

The non-parametric tests of Kruskall-Wallis and Mann-Whitney were used. Before the analyzes, normality tests (Shapiro-Wilk test) and homogeneity tests were carried out on the variables. The normality and homogeneity conditions were not satisfied; we applied the Kruskall-Wallis test (multiple rank comparison test) and Mann-Whitney test for a significativity threshold $p < 0.05$. STATISTICA 7.1 software was used for the analysis.

2- RESULTS AND DISCUSSION

2.1- RESULTS

2.1.1- Concentration of Cr, Hg, Pb and Cd in Taabo Lake sediments

The results of the analyses of the metallic trace elements carried out in the sediments during the various sampling campaigns are presented below.

The median chromium levels vary from 6.388 to 11.338 ppm for a general median of 6.980 ppm. For lead, the values are 2.360 and 49.522 ppm for a general median of 17.850 ppm. For cadmium, the minimum and maximum median values are 2.232 ppm and 3.718 ppm respectively for a median value of 2.494 ppm. The median mercury values range from 0.646 to 1.110 ppm for an overall median value of 0.685 ppm.

The quantitative distribution of TME contents in Taabo Lake sediments follows this hierarchy:

Pb > Cr > Cd > Hg.

2.1.2- Characterization of Pollution Indexes

The environmental quality of the sediments was defined by the geoaccumulation index (Igeo) and the contamination factors (CF).

- Geoaccumulation index (Igeo) in TME of sediments

The intensity of contamination of sediments by trace metals is presented by the figure below:

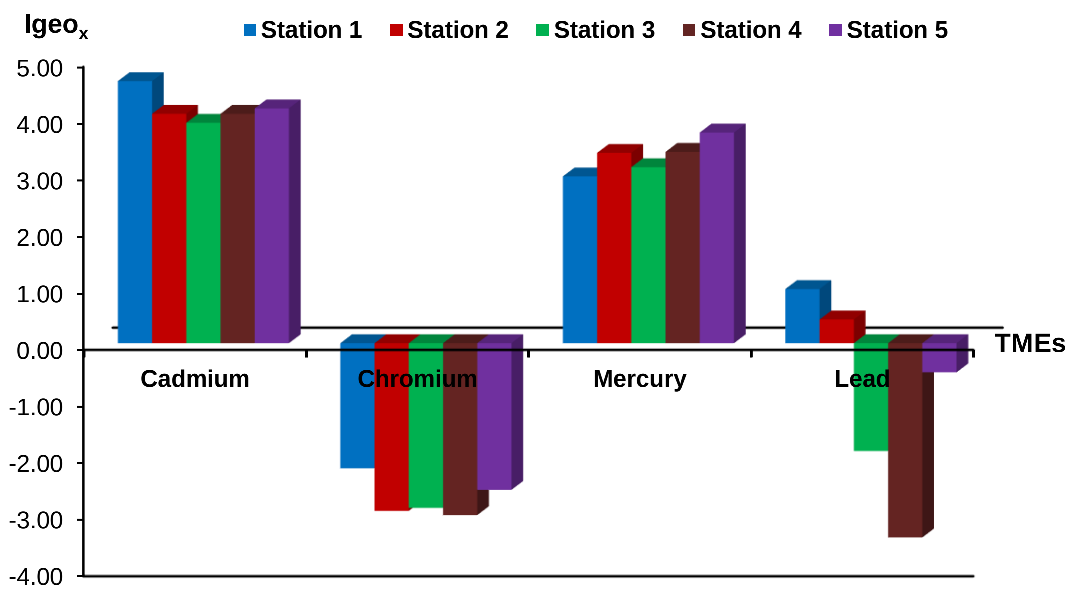

Figure 3: Taabo Lake sediment TME geoaccumulation index

Igeo values for chromium range from -3.039 to -2.211 and define sediments unpolluted by this trace element. For mercury, the Igeo admits values between 2.948 and 3.724 by which heavily polluted sediments have been established. As for lead, the values of the geoaccumulation index vary between -3.434 and 0.958 and determine non-polluted to moderately polluted sediments. The sediments are high to extremely polluted with cadmium for Igeo values ranging from 3.895 to 4.632.

In sum, the level of pollution of the sediment by these TMEs, in descending order by Igeo, is as follows:

Igeo (Cd) > Igeo (Hg) > Igeo (Pb) > Igeo (Cr)

- TME contamination factor "CF" of sediments

The figure above shows the variation in the TME contamination factor of Taabo Lake sediments.

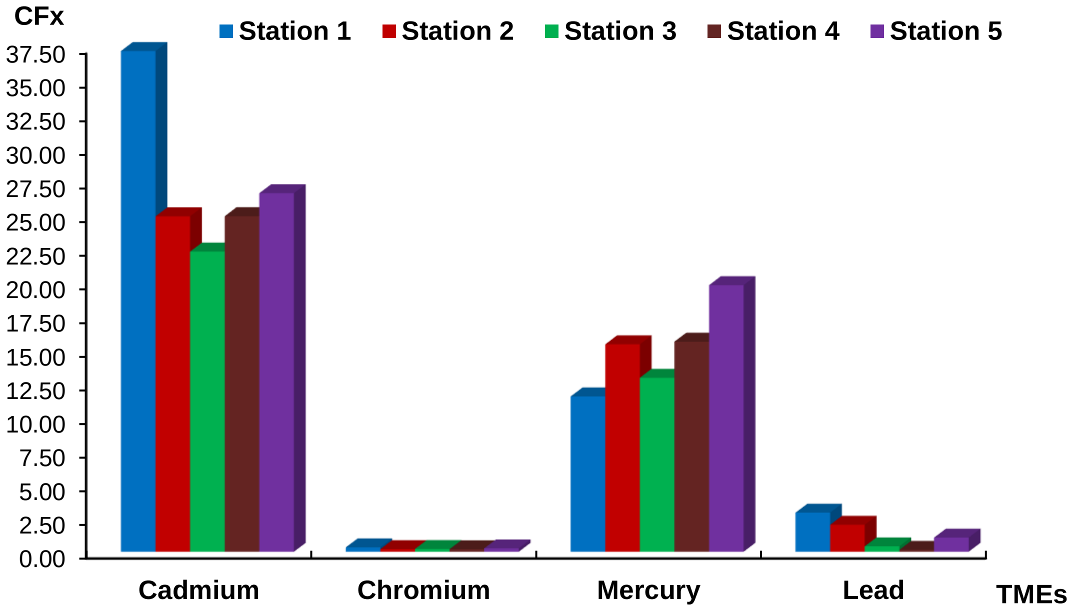

Figure 4: Variation in sediment CF from Taabo Lake stations.

The sediment contamination factor value ranges from 0.183 to 0.324 and, therefore, less than 1, for chromium reveals sediments with what is called "absent to low" contamination. For CF values greater than or equal to six (6), particularly cadmium (22.317 to 37.182) and mercury (11.576 to 19.827), sediment contamination by these TME is said to be "very high". The contamination of sediments by lead is said to be "moderate". Indeed, the CF values from the Taabo Lake sediments for lead range from 0.139 to 2.913.

2.2- DISCUSSION

TME are present in all environmental compartments because they occur naturally in them (natural sources), and multiple anthropogenic activities promote their dispersion (Amadi, 2012; Swarnalatha and Nair, 2017). Sediments, an accumulation compartment for metal pollutants, can also behave as endogenous sources of contamination, by resuspension (floods, bioturbation) or by the evolution of the speciation of TME, which will also play on their bioavailability (Benguedda-Rahal, 2012). The contamination of Taabo Lake sediments by these TME would be of anthropogenic origin and, mainly, agricultural (Irié *et al.*, 2019; Keumean *et al.*, 2020).

The median concentrations obtained in TME vary from 0.648 ppm to 49.522 ppm. These results highlight variability in metal contents. This spatial distribution of TME would result from the combination of natural factors (climate, relief) and anthropogenic factors marked by the use of chemical and organic fertilizers and pesticides in agricultural activities in the study area.

With a median concentration (6.980 ppm) of the Taabo Lake sediments, chromium was below the continental crust value (UCC) of Wedepohl (1995). However, the concentrations of cadmium and the said sediments' mercury are well above the UCC values. For lead, its median value in the sediments is approximately equal to its UCC value. Thus, polymetallic contamination of Taabo Lake sediments by cadmium, mercury and lead is noted. These results are contrary to those obtained by Diangoné *et al.* (2020) in their "Evaluation of the Metallic Pollution of the Superficial Sediments of Potou Lagoon during the Low Water Period (Littoral of Côte d'Ivoire)". This disagreement may be related to the geological nature of the study area. In their work on the sediments of the Ouladine lagoon (Grand-Bassam, Côte d'Ivoire), Keumean *et al.* (2020) recorded the element chromium as the most concentrated with 83.92 ppm against 13.75 ppm for cadmium, which remains the least concentrated of the TME in the sediments. With an average Pb content of 37.66 ppm in sediments, Djeddi *et al.* (2018) recorded a higher content than the earth's crust.

The geoaccumulation index (Igeo) being used to evaluate the contamination of sediments by TME, it emerges from the classification by the Igeo that Cd and Hg are the most polluting TME of the sediments collected at Taabo Lake. Indeed, the geoaccumulation index of cadmium and mercury have values that vary from 3.895 to 4.632 and from 2.948 to 3.724, respectively. With cadmium geoaccumulation index values of 1.85 and 1.68 of the sediments from Bonikro and Agbaou (Côte d'Ivoire), respectively, these are said to be moderately polluted (Kinimo et al., 2018). These Igeo (Cd) values are lower than those determined in the present study. In contrast, unpolluted to moderately polluted sediments with cadmium were found by Ahoussi et al., 2020 on sediments from gold panning sites in Kocoumbo (Ivory Coast). Also, Asare *et al.* (2019) reported an Igeo index value of 0.74 for sediments from Awoda, Ghana, making them low-polluted sediments. Similarly, for the "FC" contamination factor of sediments in TMEs, the order of contamination of sediments remains identical to that observed in Igeo i.e. cadmium remains the most contaminating trace element while lead remains the least contaminating. Similar observations were noted by Irié Bi *et al.* (2019) on the Ebrié Lagoon in Abidjan (Côte d'Ivoire). Also, for Keumean *et al.* (2020), sediments collected from the Ouladine Lagoon show contamination ($FC \geq 1$) for the studied TME except for Cu ($FC \leq 1$). As a result, considerable contamination ($3 \leq FC < 6$) was found at the different stations for Cd and Pb. Numerous studies have highlighted the considerable and even strong contamination of sediments by trace metal elements such as Cd, Hg, Pb, etc.And, among the TME investigated in this study, Cr, Hg, Pb and Cd have no known physiological functions and would only exert adverse effects on living organisms (Manda *et al.*, 2010; El Morhit *et al.*, 2012). Indeed, specific adverse effects of these trace elements would be generated on humans. It would be an alteration of the renal function by cadmium. As for chromium, pulmonary effects can be observed. For mercury and lead, neurological and hematological effects would be observed.

CONCLUSION

This study assessed the level of metal contamination in Taabo Lake sediments due to agricultural activities. The spatial distribution of trace metal contents revealed concentrations above the UCC values of the continental crust, except chromium. In addition, the contamination indices (Igeo and FC) showed polymetallic contamination of the sediments studied by Cd and Hg and, to a lesser extent, by Pb on all the stations of Taabo Lake, an area subject to intense agricultural activities through the use of fertilizers (mineral and organic) and pesticides.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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