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Sources and Distribution of Mercury (Hg) Residues in Sediments and Physico-Chemical Characterization of Waters in the Cotonou Channel and Lake Nokoué, Benin

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Abstract: Water is an essential resource for maintaining aquatic life and the quality of aquatic products. However, sediments are the most important place of accumulation of metal residues and their remobilization in the food chain. The objective of this work is to study the water physicochemical quality and the mercury contamination levels of the sediments in the Channel of Cotonou and Lac Nokoué. Temperature, pH, conductivity, salinity and dissolved oxygen have been measured on-situ in surface and deep water. The surface sediments have been sampled and analyzed in the laboratory using the cold vapor technique (CV-AAS) by the Direct Mercury Analyzer (DMA 80) for mercury analysis. The characterization of the sediments through the granulometric fractions shows that the channel is sandy due to marine inputs while Lake Nokoué is essentially of the silt-sandy type. Mercury concentrations in Lake Nokoué sediments (up to 130.72 µg/kg) greatly exceed geochemical natural loads (20-30 µg/kg) and reveal mercury contamination; this is the case along the channel where the distribution of these residues is very uneven due to the dilution observed at the mouth by marine inputs from the Atlantic Ocean. According to the results obtained, the sediments of the two ecosystems are of class 6, extremely polluted sediments (Igeo > 5) showing a significant risk of migration of these residues in the food chain, especially for benthic organisms.

Keywords: Mercury, Contamination, Sediments, Channel, Nokoué Lake, Ecosystem

1. Introduction

Since the Minamata conference, the scientific and professional world has mobilized for investigations and awareness on the effects of mercury in the environment and especially on public health. Africa has not stayed on the sidelines of these events, which have a global reach due to the long-range transport of various anthropogenic sources and natural sources [1]. In fact, mercury is a poison that can migrate through all the links in the food chain. It is found in fish, poultry, insecticides, fungicides, formulation of pesticides and herbicides, vegetables, edible parts of crops and in thimerosal (in vaccines). Mercury is used in fluorescent lamps [2, 3], electrical and electronic equipment [4]. It is also used in medical and measuring devices, batteries [2] and in dental amalgams [5]. Mercury is also used in the artisanal mining of precious metals [6], in the manufacture of chemical fertilizers [7], in the manufacture of fungicides [8] and in the manufacture of some vaccines [5, 9]. Multiple factors can explain its distribution in the aquatic environment, with transport by continental water currents as the main vector of redistribution. However, the hydrography of Bénin includes four basins and several bodies of water including Lake Nokoué and the of Cotonou Channel. Lake Nokoué is one of the most important brackish ecosystems in Bénin and Africa with an area of 160 km² [10]. It is a component of the RAMSAR 1018 site of natural and cultural wealth. These waters offer several assets to humans including agriculture, livestock, transport, and especially fishing. The latter is an essential sector for the economy and food in Bénin. It contributes about 75% to national fish production and contributes nearly 31% to national consumption of animal protein [11]. In its Chapter II, Article 28, the framework law on the environment in Bénin prohibits spills, runoff, discharges, direct or indirect deposits of any kind that may cause or increase water pollution. Unfortunately, several practices around and on the surfaces of our waters generate chemical pollution. This involves the installation of latrines on stilts, the use of household waste to fill the banks, the connection of several drainage networks for domestic and industrial dirty water with Lake Nokoué and the Cotonou Channel. Gasoline smuggling, road traffic, municipal, industrial, agricultural and artisanal waste are the most important sources of contamination [12, 13]. Chemical contaminants such as heavy metals, mainly cadmium, lead and mercury are contained in elements of daily use such as vehicle batteries, oil waste, batteries, medical thermometers, energy-saving lamps, dental amalgams, etc. These contaminants are distributed on the ichthyofauna, the water and especially the sediments of the aquatic environment. The sediments are of great ecological importance because animals lay eggs there, others live there, like oysters for example. In Lake Nokoué, the average lead content in the sediments (130.77 mg/kg) is nearly one hundred (100) times higher than that obtained in the water (1.45 mg/L) [14]. The dosage of lead in shrimp samples at different points in the lake reveals a strong accumulation of residues by these living organisms. On the other hand, the dosages of cadmium in the shrimp samples and that of lead and cadmium in the lake water samples are below the criterion required by the WHO in [15]. In 2011, Youssao et at. (2011) [16] indicated that the lead concentration in the organs of certain fish (*Sarotherodon melanotheron, Tilapia guineensis* and *Hemichromis fasciatus*) greatly exceeds the reference values of 0.4 mg. kg^{-1} fresh weight according to [17]. According to the mercury assessment report in Bénin [1], mercury emissions and releases are estimated at 16892.5 kg Hg/year for the air, particularly with batteries containing mercury, open burning of waste, gold mining, informal dumping of waste and skin lightening creams and soaps containing mercury. Since the Minamata incident in Japan in 1950, awareness has grown internationally of the toxicity of mercury. It is toxic at very low doses and can travel long distances to settle in areas far from the source of atmospheric emission. In Bénin, several studies have revealed the presence of mercury in different environmental matrices. MIA [1] has revealed mercury pollution in groundwater and surface water, particularly those downstream of Lake Toho, of 0.0033 mg Hg / L and 0.019 mg Hg / L respectively, due to landfilling waste at the Ouèssè sanitary landfill site. Similarly, Dovonou et al. [18] have revealed pollution of groundwater and the aquifer of the Godomey Plateau by mercury at rates between 0.0001 mg Hg/L and 0.0006 mgHg/L. This contamination has also reached the biocenosis according to the results of studies conducted by Dégila et al. [19] who revealed the presence of mercury in fish and shrimp from Lake Nokoué. This scientific article focuses on the contamination of sediments in aquatic ecosystems in southern Bénin. It aims at determining the sources of mercury in surface sediments and the explanatory factors by measuring the physico-chemical parameters of water at the surface and in depth for Lake Nokoué and the Cotonou Channel.

2. Material and Methods

2.1. Description of the Study Environment

Included between the parallels 6° 20' and 6° 30' North (Figure 1), the meridians 2° 20' and 2° 35' East, 20 km long from east to west (Kétonou-Abomey-Calavi) and wide 11 km in its North-South direction (Ouédo-gbadji - Cotonou), Lake Nokoué has an area of approximately 160 km^2 during high water periods. With the new territorial division, Lake Nokoué straddles three (3) regions: Atlantique, Littoral and Ouémé. The Cotonou channel (Figure 1) begins near Hindé (west bank) and Agbato (east bank) and crosses the city of Cotonou before emerging into the Atlantic Ocean at Placodji (west bank) and 'Akpakpa Dodomey (East bank). It is located in the south-east of Bénin about 1200 m from the port of Cotonou, between the parallels 2°26'30" and 2°26'22" North and the meridians 6°20' and 6°23' East. It is 4.5 km long by 300 m wide with an area of approximately 1.125 km^2. Its depth initially varies between 5 and 10 m.

The potential sources of mercury in the Cotonou Channel are the nearby hospitals such as the Mother and Child Hospital (Homel), the Dantokpa market and the Atlantic Ocean which exerts a strong influence due to high and low tides. Continental inflows also come from the city of Cotonou, most of whose gutter outlets lead there.

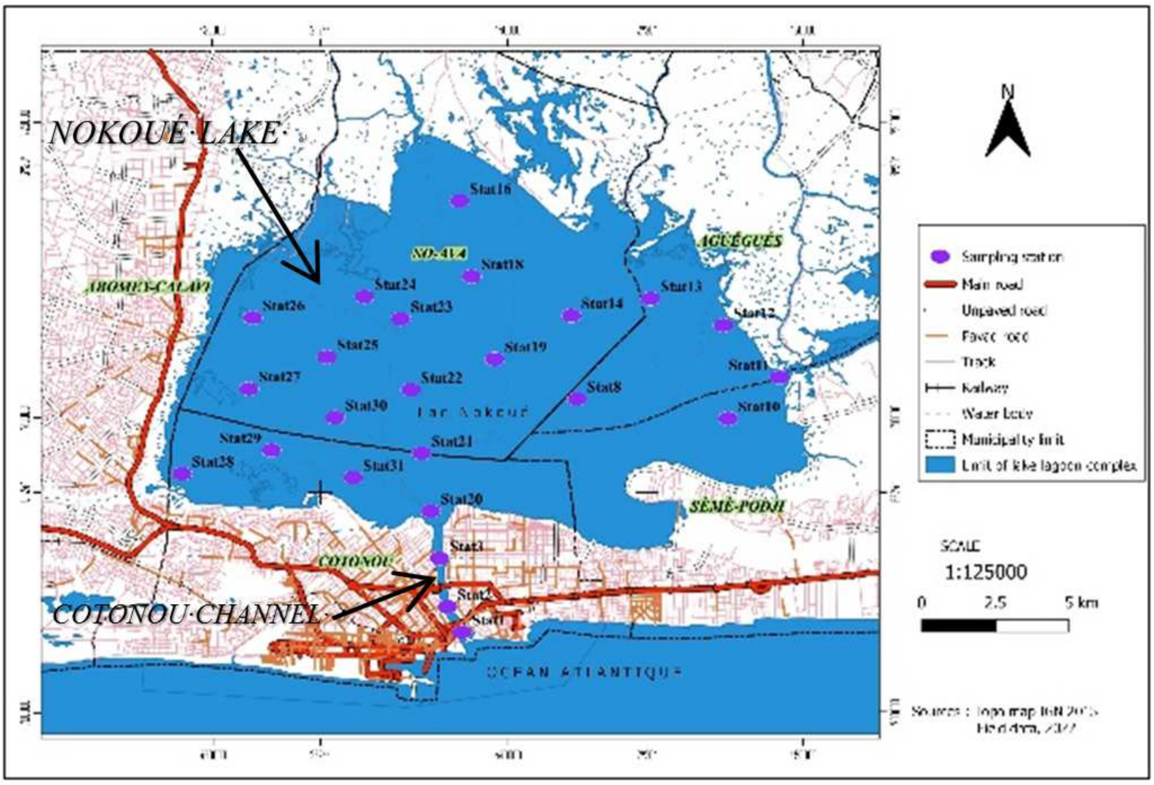


Figure 1. Location of sampling points on Lake Nokoué and the Cotonou Channel.

Lake Nokoué is under the influence of several town halls including those of Abomey-Calavi and Sèmè-kpodji and Porto-Novo. Different activities have been identified as potential sources of mercury (Figure 1). The hydrography of Bénin presents several rivers coming from the southern zone but also from the northern part of Bénin which end in Lake Nokoué with their pollutant load.

2.2. Sampling

We collected the surface sediments using a skip and packed them in previously sterilized and labeled zip bags. At each station, we take three samples to make a composite sample. These samples are stored in a cooler containing cold packs at 4°C and transported to the laboratory for appropriate processing. Once in the laboratory, the sediments are placed in a freezer.

Water samples were taken at the surface and at depth for the measurement of physico-chemical parameters in the field. The sampling container is rinsed three times with site water before measuring the parameters in the water.

2.3. Measurement of Physico-Chemical Parameters

The physicochemical parameters were determined in the field with a Multi 3630 IDS type multiparameter. It is a digital device equipped with several probes which allows quick and reliable measurements of pH, redox potential, conductivity, dissolved oxygen and turbidity according to the incorporated sensors. The probe makes it possible to measure the various parameters directly in the water column at different depths.

2.4. Sample Processing and Mercury Analysis

The repair of the sediment samples took place in three main stages. These are drying, grinding and sieving. During drying, the sediment samples are placed in labeled aluminum foils in the shape of a cobblestone. They are then weighed using a very sensitive KERN PLS scale. The mass is noted in a register and the samples are then placed in a memmert UF 110 brand oven set at 40°. The samples remain there for 3 to 5 days and are recovered at constant weight.

Total mercury was analyzed in the laboratory using the Cold Vapor-Atomic Absorption Spectrometry (CV-AAS) technique by the Direct Mercury Analyzer (DMA 80) in the fine fraction of the sediments [20].

2.5. Particle Size Determination

Granulometry aims to measure the size of the elementary particles which constitute the sediments generally made up of pebbles, gravel, sand, clay, etc. and the size fractions are quite numerous. The sediments are cleared of plant debris and bone fragments and before passing through a sieve. The sieving method using an automaton was used. It consists of measuring the weight of material that passes through the calibrated meshes of a sieve cloth. The sieves are superimposed by decreasing mesh and the weight of material retained on each sieve is measured. This operation can be carried out dry, and by vibrating the entire sieve column, for relatively large grains. It was carried out with a Retsch AS200 basic brand mechanical sieve and the portions weighed with a KERN PLS brand scale. We then determined the nature of the sediments using the triangle of soil textures and a nomenclature table.

2.6. Geoaccumulation Index (Igeo)

The accumulation of mercury residues in a receiving environment [21] is an increasingly significant risk in developing countries. The geoaccumulation index (Igeo) makes it possible to calculate its intensity [22] in surface sediments, receptacles for metallic pollutants. The determination is made with reference to pre-industrial concentrations of metals during the 19th and 20th centuries, associated with human activities. The formula of [23] made it possible to calculate the Igeo, i.e.:

$$I_{geo} = Log_2\left(\frac{C_{Hg}}{1.5B_{Hg}}\right) \quad (1)$$

The geochemical background of mercury (B_{Hg}) we use is: 0.02 mg/kg [24].

2.7. Statistical Data Analysis

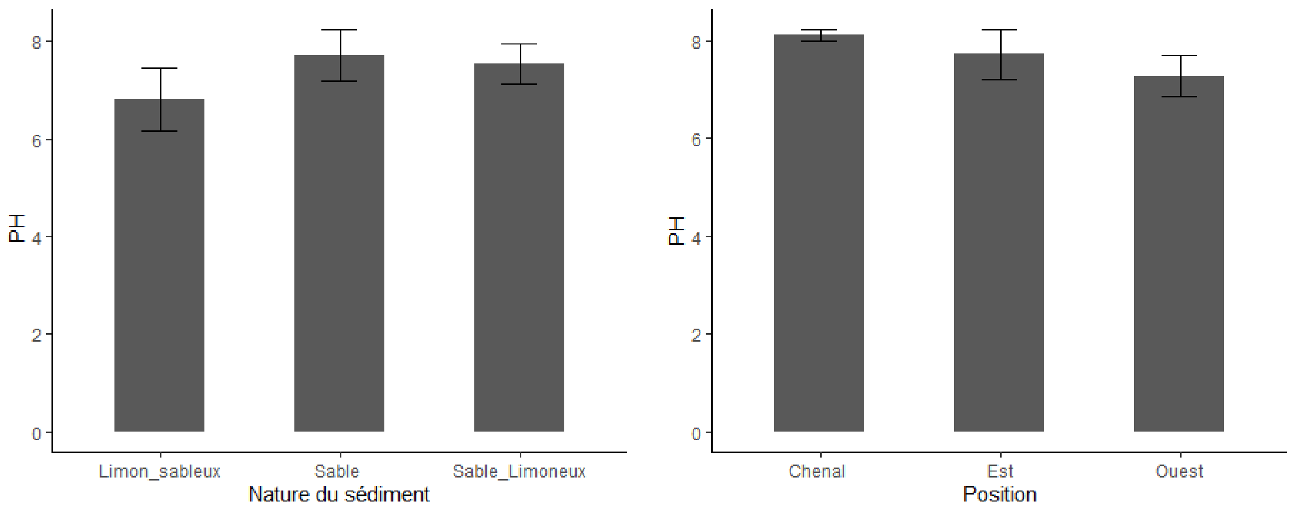
All statistical analyzes are performed with version 4.0.0 of the R statistical software [25] and Excel software. We have used boxplots and barplots to explore the variations of physico-chemical parameters on the type of ecosystem (Channel, East and West) and the measurement levels (surface and depth) on the one hand and the variations of the mercury concentration depending on the nature of the sediment and the types of ecosystems on the other hand. An analysis of variance model with two fixed factors is used to separately study the significance of the difference in the means of each physico-chemical parameters according to the types of ecosystems and the levels of measurement. Since the experimental design is completely unbalanced and at the level of the channel there is only one type of sediment (sand), we used a one-way ANOVA to separately study the effect of the nature of the sediment and the ecosystem type on mercury concentration. Turkey's method is used for multiple comparison of means with the multcomp package.

3. Results and Discussion

3.1. Physico-Chemical Characterization of Water

3.1.1. pH

Figure 2 shows the variations in water pH at the different stations. The measurements took place in December, which corresponds to a dry period or low water in southern Bénin. The pH values recorded are between 6 and 9. The highest value is 8.55; obtained at station 14, it is located in Ouédo. The lowest value is 6.34; obtained at station 28 located in Godomey. Compared to the aquatic development standards mentioned above, we can say that the lake remains a safe habitat for the species with regard to this parameter.



a) Variation with fraction size *b)* Variation with the position

Figure 2. *Variation of the pH on the different stations.*

A variation of about 2.21 is observed on this parameter during our study in the month of December. The pHs generally approach neutrality. A variation of about 1.7 was found by [26]; 1.75 in June and 1.55 in September by [18]. We find that regardless of the season of the year, the variation of this parameter on Lake Nokoué is about 2.

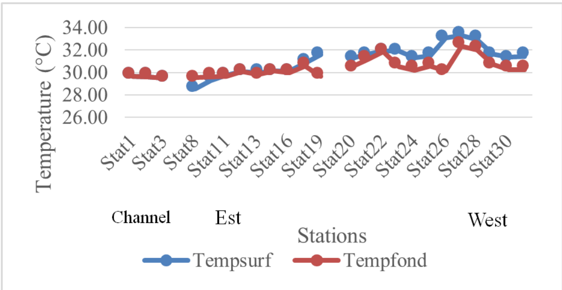
3.1.2. Temperature

Figure 3 shows the evolution of the temperature on Lake Nokoué and Cotonou Channel. On the surface, the temperature can reach values of 33.31°C. It is raised at stat27 located in Abomey-Calavi. The temperature at the bottom at this same point constitutes the highest value, 32.32°C. The lowest values of surface and bottom temperatures on the lake are respectively 28.56°C and 29.56°C observed at stations 8 (Tchonvi) and station 2 (Channel of Cotonou). During the day, the temperature increases by about 4°C at the surface of the lake and 3°C at the bottom. The temperature variations between the bottom and the surface are small. At this time of year, aquatic life is preserved.

Table 1. *Analysis of variances of salinity, DO and water temperature.*

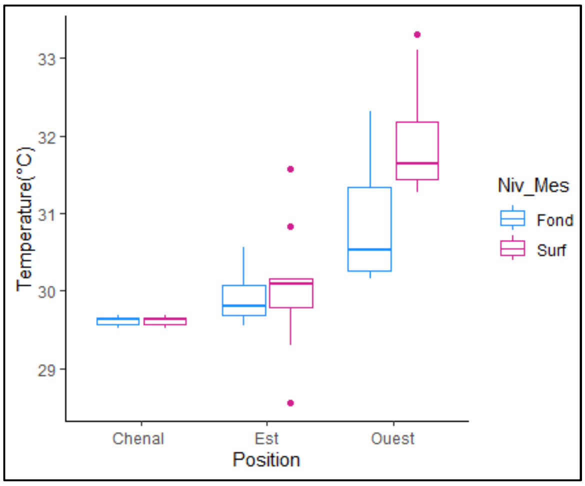
	N	Salinity	dissolved oxygen	Temperature
Position				
Channel	6	22.27± 0.3^{b}	7.12± 0.06^{a}	29.61± 0.08^{a}
East	18	5.13± 6.14^{a}	6.97± 1.61^{a}	29.98± 0.63^{a}
West	24	8.71± $^{7.54A}$	6.29± 1.67^{a}	31.41± 0.92^{b}
Measurement level				
Bottom	24	13.22± 7.61^{b}	6.37± 1.44^{a}	30.36± 0.79^{a}
Surface	24	4.9± 6.95^{a}	6.93± 1.65^{a}	30.94± 1.26^{b}

N: Number of measures; *DO:* dissolved oxygen.



Legend: Stat: station; Tempsurf: Temperature on surface; Tempfond: Temperature at the bottom

a) Variation Curve



Legend: Chenal: Cotonou Channel, Est: East Ouest: West

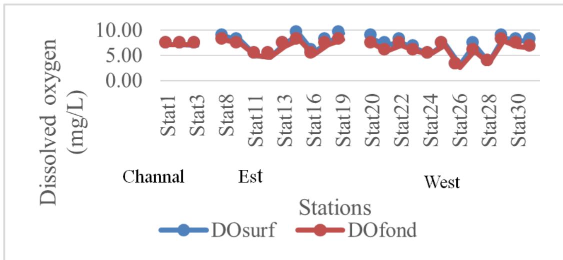
b) Variation Plot

Figure 3. *Variation of the temperature on the different stations.*

The temperature is homogeneous in the Cotonou Channel and to the East except at stations 8 and 19, while to the west Lake Nokoué has a slightly higher temperature except at station 22. Dovonou et al. [18], recorded temperature variations ranging from 25.4°C to 34°C in June and from 27°C to 30°C in September. The variation is therefore around 3°C in the short rainy season (September) and around 8.6°C in the long rainy season. In our study we record in the month of December (long dry season) a maximum variation of about 4°C. It appears that aquatic species in Nokoué are subject to a greater variation in temperature in the rainy season than in the dry season.

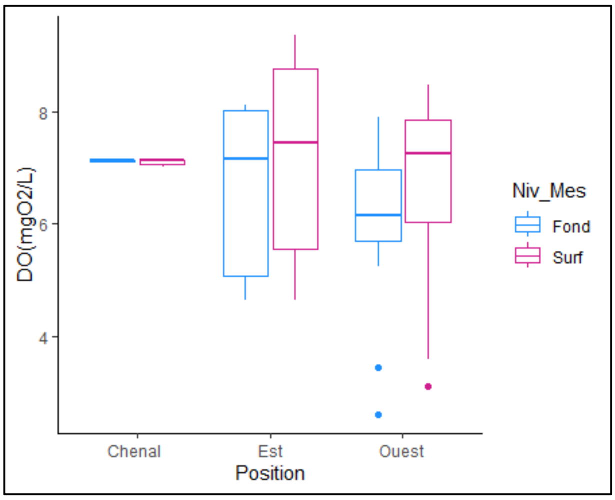
3.1.3. Dissolved Oxygen (DO)

Figure 4 presents dissolved oxygen at the surface and at the bottom of Lake Nokoué and the Cotonou Channel. The highest surface value is observed at station 19. It is 9.37 mg/L and is located in Ganvié. The smallest surface value is 3.12 mg/L; recorded at station 26 (Abomey-Calavi). With regard to dissolved oxygen at the bottom, it is still station 26 which displays the lowest value (2.61 mg/L) but it is station 14 located in Ouèdo which has the highest value (8.11 mg/L). Dissolved oxygen varies very slightly between the bottom and the surface of Lake Nokoué [27]. The majority of stations present values in line with the WHO standard which recommends at least 7 mg/L of dissolved oxygen in fresh water except stations stat11 (Kétonou), stat12 (Aguégué), stat16 (Ouédo), stat23 (Ganvié), stat24 (Ganvié), stat26 (Abomey-Calavi) and 8 (Godomey). Data from stations 20 and 21 are missing because we had a hardware failure in the field.



Legend: Stat: station; DOsurf: DO on surface; DOfond: DO at the bottom

a) Variation Curve



Legend: Chenal: Cotonou Channel, Est: East Ouest: West

b) Variation Plot

Figure 4. *Variation of the dissolved oxygen on the different stations.*

Dissolved oxygen is homogeneous in the Cotonou Channel [27] while Lake Nokoué has a slightly higher content at the surface than at depth except at a few stations.

The highest dissolved oxygen value recorded at the surface on Lake Nokoué in December is 9.37 mg/L and 8.11 mg/L at the bottom. Dovonou et al. [18] recorded a maximum value of 7 mg/L in the rainy season (June) at the level of the Sô River. Lake Nokoué then does better in the dry period when external inputs are lower. The lowest dissolved oxygen values are observed in heavily inhabited areas, i.e. the western area of the lake and the points located not far from the banks (Kétonou, Tchonvi). This anthropogenic pressure is therefore responsible for this situation observed at certain lake stations. The same reason had already been mentioned by Mama et al. [26]. These points are stress microecosystems for living aquatic organisms.

3.1.4. Salinity

Lake Nokoué is saltier at the bottom than at the surface at all the stations considered (Figure 5). Basically, the two (2) stations located in Ganvié displays the highest salinity value (23.63). The highest surface salinity value is noted at station 1 (22.55) located in the channel. The lowest salinity values are observed at station 11 (0.21) both at the bottom and at the surface. This station is located in Kétonou. At this time of year, these waters are suitable for brackish, marine or euryhaline freshwater species. The salinity is homogeneous in the Cotonou Channel while Lake Nokoué has a higher salinity at depth than at the surface except at stations 11 and 19 to the east. According to the results of Youssao et al. [27] the salinity varies greatly according to the tides.

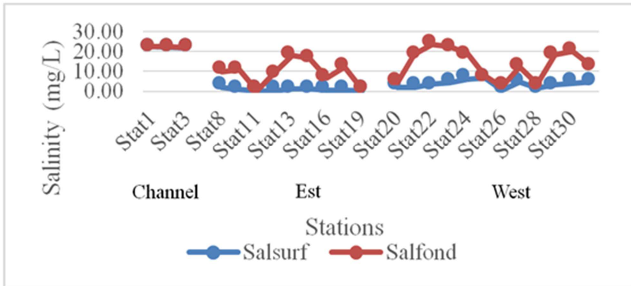
The background salinity in the month of December is around 25 and even at points quite far from the Cotonou channel (Station 22, Ganvié). On the surface, the channel remains the saltiest zone. This can be explained by the low intrusion of water from the Ouémé and Sô during this period of drought. We also notice through this study that the variation of the salinity from the bottom to the surface is quite significant at all the other points except those of the channel. This can be explained by the fact that the marine intrusion in Lake Nokoué takes place at the bottom.

Table 2 relates to the descriptive statistics (mean ± standard deviation) of salinity, dissolved oxygen and temperature according to the ecosystems and the level of measurement. The average values followed by the same letter in each column are not statistically different at the 5% threshold level.

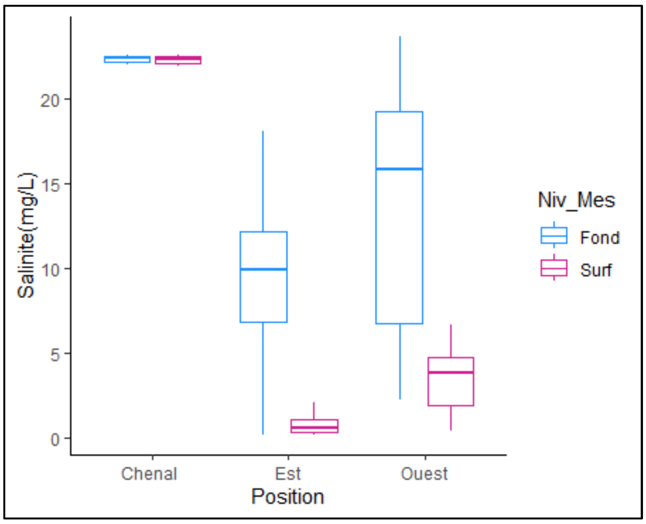
The analysis of variance shows that the difference at the ecosystem level is significant for the physico-chemical parameter salinity ($F_{(2.42)}=28.05$ and $p<0.001$). Indeed the salinity is higher at the level of the channel (22.27 ± 0.3 mg / L) than on the east side (5.13 ± 6.14 mg / L) and West (8.71 ± 7.54 mg /L) of the lake. Similarly, the salinity is higher at the bottom than at the surface of the lake ($F_{(1.42)}=14.21$ and $p<0.001$) except at the level of the channel where the difference is not significant.

Dissolved oxygen does not vary significantly from one ecosystem to another (see Table 1); $F_{(2.44)}=1.3$ and $p=0.28$) and nor depending on the level of measurement ($F_{(1.44)}=1.57$ and $p=0.22$).

The temperature varies significantly depending on the ecosystems ($F_{(2.44)}= 28.32$ and p $p<0.001$) and depending on the level of measurement ($F_{(1.44)}=8.16$ and $p= 0.0065$). The multiple comparison of the means shows that the temperature is higher at the level of the West ecosystem (31.1°C) than at the level of the channel (29.0°C) and the East (29.6°C). In the same way, the temperature is higher at the surface than at the bottom regardless of the ecosystem (see figure 5).



Legend: Stat: station; Salsurf: Salinity on surface; Salfond: Salinity at the bottom
a) Variation Curve

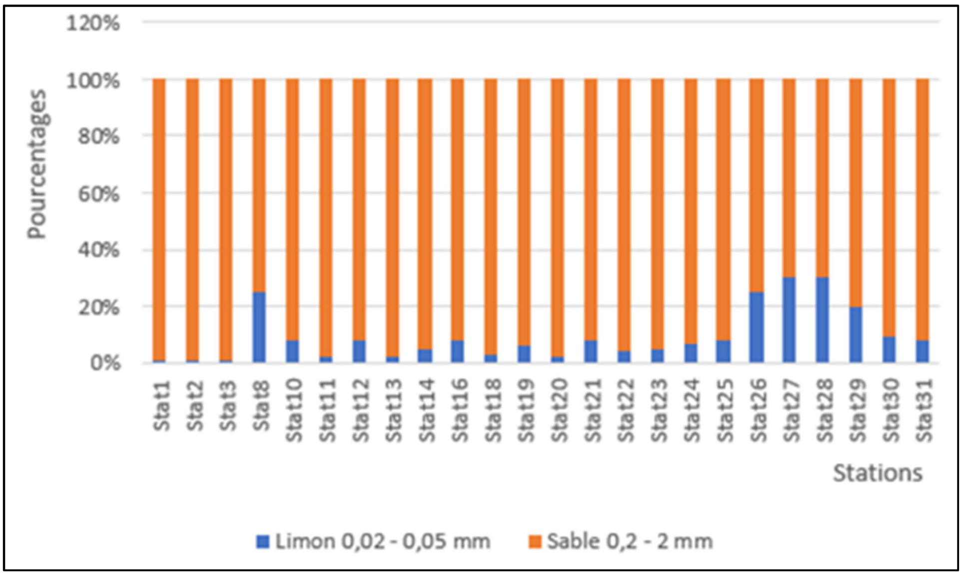


Legend: Chenal: Cotonou Channel, Est: East Ouest: West
b) Variation Plot

Figure 5. *Variation of the salinity on the different stations.*

3.1.5. Characterization of Sediments

The surface sediments of the lake are dominated by sand. The sediments at the level of the channel (Stations 1, 2, 3) are sandy in nature with 99% sand (Figure 6). The same observation is made at stations 11, 13, 14, 18, 20, 22 and 23 but between 91-95% sand. The sediments at stations 8, 10, 12, 16, 19, 21, 24, 25, 26, 29, 30 and s31 are sandy-loamy in nature with 70-95% sand. Sandy silt is found at stations 28 and 27 with less than 70% sand.



Legend: Stat: station

Figure 6. *Distribution of particle size fractions of sediments by station.*

Recent sediment deposits in Lake Nokoué consist of sand and silt in different proportions. Areas rich in silt are the most important sites for carrying out studies on pollutants because they better retain heavy metals and others.

3.2. Mercury Pollution Study

3.2.1. Mercury Levels in Sediments

The concentration of mercury in the sediments of the lake varies between 30.48 µg/kg and 130.72 µg/kg. The highest value was recorded at Ouédo (station 16) and the lowest value at Ganvié (Station 24). Certain points also located in Ganvié give values higher than the natural load (20 µg/Kg-30 µg/Kg) such as the stations 22; 19; 23; 25 and 24. The values of this element in these areas of the lake may have an anthropogenic origin (certain batteries, cosmetic products, discharge, etc.). The average mercury load in the sediments of the different areas exceeds the natural loads indicated (20 µg/Kg – 30 µg/Kg). The high load observed in organic matter in the waters and sediments also allows us to assert that the methylation of mercury [29, 30] is highly probable because the sites are contaminated by organic waste (animal waste, faeces, waste from fishing activities, etc.).

Table 3 represents the evolution of the mercury content in the sediments of the Cotonou channel and Lake Nokoué at the stations located at the East (town halls of Ouémé and Porto-Novo) and West (Abomey-Calavi town hall). The average is 95.32 µg/kg in the Cotonou Channel. The estuary is the least contaminated point and the most contaminated point near missébo. This may be due to the dumping of waste and other manufactured products on the banks at this point in the channel. In general, the Cotonou channel is influenced by solid and liquid discharges from the inhabitants of areas such as Xwlacodji, waste water from the HOMMEL hospital, waste from fabric workers tinted with missébo and Tokpa, then fishing waste.

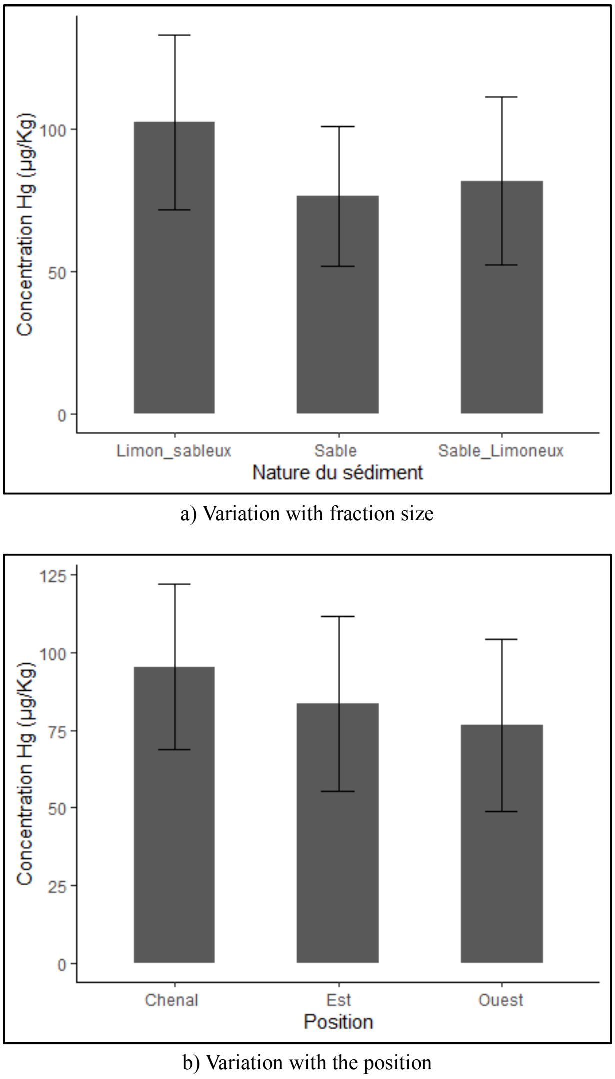


Figure 7. *Mercury content in the sediments of the Channel.*

The average concentration is 83.43 µg/kg in Nokoué Lake. This zone is influenced by the contributions of the Ouémé River and the liquid and solid discharges from the inhabitants of the lake and then from the shores. The most contaminated sediments are located in Ouédo and the least contaminated in Ekpè. The contamination of the sediments in this part of the lake can be explained by the inflow of water from the Ouémé River which runs through the agricultural lands of northern Bénin. The leaching of these soils rich in phytosanitary products probably loads the waters of the Ouémé with mercury residues. What comes to flow into Lake Nokoué.

The western side of Lake Nokoué is the most inhabited lake area. It is influenced by the contributions of the Sô and Djonou rivers and rejections of all kinds from the inhabitants. The average concentration is 76.46 µg/kg. The smallest value is recorded in Ganvié but the largest is in Godomey not far from Djonou (Table 3).

As for the statistical test, the p-value (0.5994) is greater than 0.05. There is no significant difference between the mercury contents of the different areas. Figure 8 shows a classification of the different zones according to the mercury contamination after carrying out the statistical test.

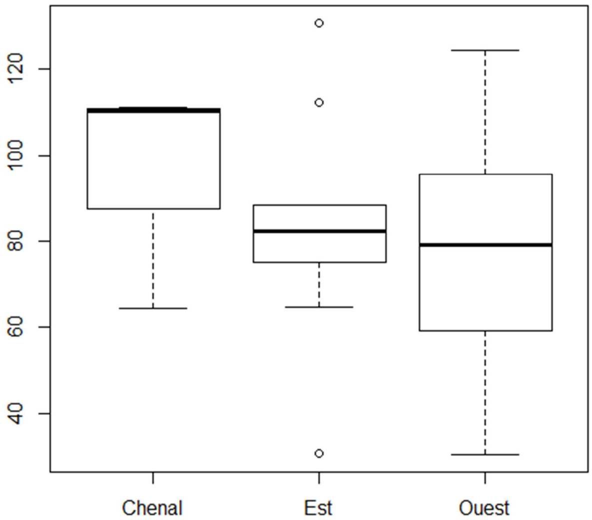


Figure 8. *ANOVA test result for mercury.*

The descriptive statistics (mean ± standard deviation) of the concentration of mercury and pH according to the ecosystems and the nature of the sediment are presented in Table 2. The average values followed by the same letter in each column are not statistically different at the 5% threshold.

Table 2. *Analysis of variances of sediment Hg concentration and water pH.*

	N	Hg-concentration	pH
Nature of the sediment			
S_loam	2	102.69 ± 30.66^{a}	6.8 ± 0.65^{a}
Sand	10	76.56 ± 24.74^{a}	7.71 ± 0.53^{a}
S_sand	12	81.96 ± 29.37^{a}	7.54 ± 0.41^{a}
Position			
Channel	3	95.32 ± 26.69^{a}	8.11 ± 0.12^{b}
East	9	83.43 ± 28.09^{a}	7.72 ± 0.51^{ab}
West	12	76.48 ± 27.68^{a}	7.28 ± 0.43^{a}

The analysis of variance shows that the concentration of mercury does not vary according to the nature of the sediment (F (2.21)=0.75 and p=0.483) nor according to the type of ecosystem (F (2,21)=0.590 and p=0.563). On the other hand, the pH varies according to the type of ecosystem (F (2.21)=5.331 and p=0.013) but does not vary according to the nature of the sediment at the threshold of 5% (F (2.21 =2.972 and p=0.073). Indeed, the pH at the level of the channel (8.11±0.12) is statistically different from the pH at the level of the East (7.72±0.51) and the West (7.28±0.43) ecosystems which are identical.

3.2.2. Sources of Mercury in Sediments

The results in Table 3 indicate two main sources of mercury in the Cotonou Channel, the Homel and the Dantokpa market with respective Hg contents of 111.06 and 110.40 µg/kg.

Table 3. *Localities – potential sources of Hg (C in µg/kg).*

Area	Stat	S_N	C_Hg	Locality
	Stat1	Sand	64,50	Mouth of Channel
Cotonou		Sand	111,06	Homel
	Stat3	Sand	110,40	Dantokpa
	Stat8	S_loam	112,19	Tchonvi
	Stat10	S_loam	30,60	Ekpè
	Stat11	Sand	82,40	Kétonou
Sèmè-kpodji and	Stat12	S_loam	74,96	Aguégué1
Porto-Novo	Stat13	Sand	85,33	Aguégué2
Townholls	Stat14	Sand	88,30	Aguégué3
	Stat16	S_loam	130,72	Ouédo1
	Stat18	Sand	64,57	Ouédo2
	Stat19	S_loam	81,78	Milieu du Lac
	Stat20	Sand	33,85	Agbato1
	Stat21	S_loam	83,51	Agbato2
	Stat22	Sand	77,11	Ganvié1
	Stat23	Sand	48,09	Ganvié2
	Stat24	S_loam	30,48	Ganvié3
Abomey-Calavi	Stat25	S_loam	70,54	Ganvié4
Townholl	Stat26	S_loam	100,28	Abomey-Calavi1
	Stat27	S_sand	81,01	Abomey-Calavi2
	Stat28	S_sand	124,36	Godomey1
	Stat29	S_loam	77,43	Godomey2
	Stat30	S_loam	95,73	Ladji
	Stat31	S_loam	95,32	Ladji
		Minimum	*30,48*	
		Maximum	*130,72*	
		Mean	*81,44*	

S_loam: Sandy_loam - S_sand: Silty_sand – Stat: Station.
NB. Here are presented the stations where we found sediments (24 stations).

In the eastern part of Lake Nokoué, the localities of Tchonvi and Ouèdo have been identified as the main sources of mercury contamination of the sediments with respective Hg contents of 112.19 and 130.72 µg/kg. While in the western part of Lake Nokoué, the localities of Abomey-Calavi (Station 26) at the pier and Godomey (Station 28) have been identified as the main sources of mercury contamination in sediments with Hg content of 100.28 and 124.36 µg/kg respectively.

The mercury concentrations in the sediments of Nokoué exceed the natural loads of 30 µg/Kg and 20 µg/kg recorded respectively by the authors Gobeil et al. [28] in the Loire and

Fabbri et al. [31]. We can then say that the sediments of the Nokoué Lake are contaminated. Mercury contamination in Lake Nokoué is of anthropogenic origin. Contaminants are dumped directly into the waters by local residents or drained into this body of water on the one hand by the Ouémé river which crosses higher cultivation areas and the Sô river on the other hand. Mercury assessment studies in sediments are both scarce in Bénin and in the sub-region. This can be explained by the complexity of the standardized methods for measuring mercury or a lack of equipment. Furthermore, [21] evaluated the mercury content in sediments from an aquaculture farm in the lagoon environment of Aghien in Bingerville. The mercury content varies between 0.16900±1.6400 mg/kg and 0.17700±2.0400 mg/kg while it varies between 0.0304817 mg/kg and 0.1307241 mg/kg on Lake Nokoué. The concentrations of mercury in the sediments of the complex exceed the natural loads but they are less polluted than those of this lagoon system of the Côte d'Ivoire and more polluted than the sediments of the rivers of the Town Halls of 2KP reported by Youssao Abdou Karim et al. [20] in an area of cotton growing and artisanal small-scale gold mining.

3.2.3. Assessment of Sediments' Degree of Contamination

Table 4 shows the geoaccumulation index of the different stations. It indicates contamination at most stations except stations 10 (Ekpè), 20 (Cotonou), 23 (Ganvié) and 24 (Ganvié). These points are located far from the banks, in areas of strong settlement in Acadja or uninhabited.

Table 4. *Mercury geoaccumulation index.*

Stat	%_Sa	%_Si	S_N	Stat	Igeo	Position
Stat1	1%	99%	Sand	Stat1	6,76	Chenal
	1%	99%	Sand		7,30	Chenal
Stat3	1%	99%	Sand	Stat3	7,29	Chenal
Stat8	25%	75%	S_loam	Stat8	7,31	Est
Stat10	8%	92%	S_loam	Stat10	6,01	Est
Stat11	2%	98%	Sand	Stat11	7,00	Est
Stat12	8%	92%	S_loam	Stat12	6,91	Est
Stat13	2%	98%	Sand	Stat13	7,04	Est
Stat14	5%	95%	Sand	Stat14	7,07	Est
Stat16	8%	92%	S_loam	Stat16	7,46	Est
Stat18	3%	97%	Sand	Stat18	6,76	Est
Stat19	6%	94%	S_loam	Stat19	6,99	Est
Stat20	2%	98%	Sand	0	6,11	West
Stat21	8%	92%	S_loam	1	7,02	West
Stat22	4%	96%	Sand	2	6,94	West
Stat23	5%	95%	Sand	3	6,46	West
Stat24	7%	93%	S_loam	4	6,01	West
Stat25	8%	92%	S_loam	5	6,85	West
Stat26	25%	75%	S_loam	6	7,20	West
Stat27	30%	70%	S_sand	7	6,98	West
Stat28	30%	70%	S_sand	8	7,41	West
Stat29	20%	80%	S_loam	9	6,94	West
Stat30	9%	91%	S_loam	Stat30	7,15	West
Stat31	8%	92%	S_loam	Stat31	7,15	West
			Minimum		*6,01*	
			Maximum		*7,46*	
			Mean		*6,92*	

-S_N: Soil Nature -%_Si: percentage of Silt -%_Sa: percentage of Sand.

The most contaminated points are located in the Cotonou channel (Stations 1, 2 and 3), in Ouèdo (Station 16) and Godomey (Station 28).

The values of the geoaccumulation index vary from 6.01 to 7.46 with an average of 7.46 obtained on loamy soils. This index is independent of the nature of the sediments.

According to the results obtained, the sediments of the two ecosystems are of class 6, extremely polluted sediments (Igeo > 5). This result is that obtained by [22].

3.2.4. Correlation Studies

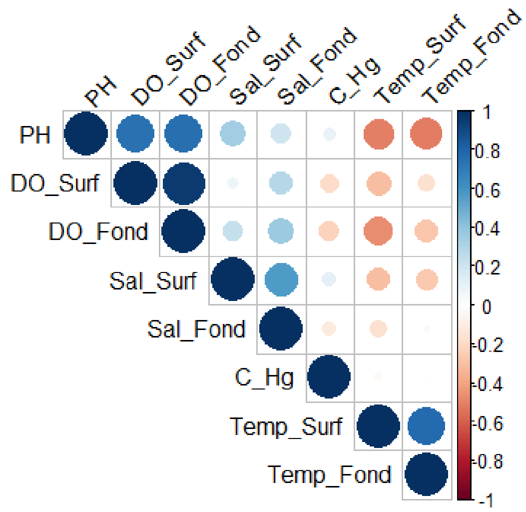


Figure 9. *Correlogram of physico-chemical parameters.*

The intensity of the color and the size of the circles are proportional to the correlation coefficients.

The correlation between the different physico-chemical parameters is low. Except for temperature measured at the bottom and at the surface (r=0.77 and $p<0.0001$), dissolved oxygen measured at the bottom and at the surface (0.96 and $p<0.001$), pH and dissolved oxygen measured at the surface (0.74, and $p<0.001$) and pH and dissolved oxygen measured at the bottom (0.75 and $p<0.001$). The mercury content is not correlated with the physicochemical parameters of the water either at the surface or at the depth.

4. Conclusion

It emerges from this work that the sources of mercury input are not only local (rivers and lakes), they are also distant because mercury is transported in the ecosystem via rivers and streams. The sediments of Lake Nokoué are undeniably contaminated by mercury. The lagoon complex is the receptacle of pollution which, in places, creates conditions of stress caused to living organisms, which is justified by a more marked lack of dissolved oxygen at depth than at the surface in Lake Nokoué. The sandy sediments of the channel did not prevent the accumulation of Hg residues from local sources. Consumers of benthic organisms must be cautious as a precautionary measure and these organisms, although resistant, can be affected because of their ecology.

5. Recommendations

Given the lack of information on the contamination of sediments by toxic metals in general and mercury in particular, we suggest that studies be carried out in order to monitor this contaminant in our bodies and waterways. Products containing mercury and its derivatives should be reduced or eliminated if possible. For the protection of aquatic ecosystems, occupants must be made aware of the health risks induced by the release of contaminants into surface water.

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