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Seasonal and spatial variation of trace elements (Cd, Pb, Ni, Cu, Cr, As and Hg) in the waters of the Lake Nangbéto in Togo

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ABSTRACT

Developing countries are encountering many difficulties to cope with water supply and sanitation. In these countries, not only that there is insufficient drinking water infrastructure but also poverty and ignorance push people to use surface waters (lake and river water) for their daily needs. The Lake Nangbéto was built in 1987 on the Stream of Mono River for hydroelectricity production. Today, the watershed of Mono River faces numerous environmental problems including soil and water pollution with trace elements, as well as pesticide residues and hydrocarbons. The aim of the study was to analyze trace elements (Cd, Pb, Ni, Cu, Cr As and Hg) in the waters from Lake Nangbéto and its surroundings in order to assess their quality. Water samples were collected in polyethylene bottles and were acidified to 1% with nitric acid. The trace elements were determined by Atomic Absorption Spectrometry. From the results obtained, the waters of Lake Nangbéto and its surroundings are contaminated for all seasons, especially by cadmium, lead and mercury; with average concentration of 9.21 and 6.80 µg/L for cadmium, 14.38 and 42.53 µg/L for lead; respectively in the rainy season and dry season and 8.04 µg/L for mercury in the dry season. The pollution factors for cadmium were 3.07 times and 2.27 times the World Health Organization (WHO) standard, 1.44 and 4.25 times for lead; respectively in the rainy season and dry season and 1.34 times for mercury in the dry season. The other elements analyzed showed low concentrations compared to the standards set by the WHO for drinking water.

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INTRODUCTION

The growth in all sectors of development on our planet has serious consequences on the environment and human health.

The industrial, agricultural and urban explosion is inevitably accompanied by various pollution problems of all ecosystems, in particular the aquatic environment (Rao et al., 2007; D'Adamo et al., 2008). In Togo, there is a significant number of artificial lakes created as a result of the construction of dams on rivers. The Lake of Nangbéto, built on the Mono River for hydroelectricity production, which is the subject of this study, is among these lakes. The population of the Mono plain in 2010 was 3,375,759 (Mouton and Brachet, 2015).

This lake not only provides, drinking water for the lakeside population but also a large quantity of fish. In fact, apart from the officials of the Hydroelectric Energy Company (CEB) plant and their families with access to

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drinking water from the tap, the rest of the villages inhabited by the large number of fishermen or not along of the Lake, are without drinking water and drink directly from the lake without any treatment. The wastewater from the Anié sugar refinery, discharged into the Anié (tributary of the Mono) and the solid waste thrown into the open air in the Mono plain and also the domestic effluents from the towns crossed by the Mono river, are all discarded without any treatment.

Thus, the Lake Nangbéto is exposed to pollutants coming from many human activities upriver (Cultivation of cotton, sugar cane, cereals in the plain; Anié sugar factory, wastewater from the towns of Atakpamé, Sokodé, Sotouboua and Anié). Indeed, this Lake is located in the Mono watershed, which comprises an area of 24,000 km² and the Mono watershed that feeds it is 15,700 km² (UNESCO, 2008).

The main tributaries of Mono river, Ogou and Anié rivers, are located upriver of the lake and collect the surrounding pollutants and discharge them into the lake. It is therefore important to identify the pollutants present in the ecosystem of this lake in order to be able to quantify them at the trace and ultra-trace concentration using reliable, sensitive and reproducible analytical methods. The results from this study could be useful for the establishment of a real policy, for the efficient and sustainable management of this lake.

Some trace elements are chemicals that represent a danger for aquatic life and human health. Some are essential and are only toxic when their concentrations (Cu, Ni, Zn etc.) exceed a threshold but, others (Hg, Pb, Cd and As) have no biological role and are potentially toxic to living organisms (Miquel, 2001a; Chiffoleau, 2001). Due to their non-biodegradability and their high persistence, trace elements can be very harmful or even fatal (Boucheseiche et al., 2002) because of their ability to be bioaccumulated by aquatic organisms increasing their concentrations compared to those in the biotope (Ogindo, 2001; Manda et al., 2010). Thus, the contamination of aquatic ecosystems by trace elements remains an increasingly worrying environmental problem (Belhoucine, 2012). In addition, since the installations of the Lake Nangbéto in 1987, few studies have assessed the level of trace elements contamination of the waters from Lake Nangbéto and its impact on their bioaccumulation by animal species in this lake.

Assessment of heavy metal pollution of some fish from the Lake Nangbéto (Tchaou, 2012) and the negative impacts related to the construction of the dam; especially the ecological and socio-economic problems (UNESCO, 2008) have already been addressed. The objective of the present study is to assess the trace element content (Cd, Pb, Ni, Cu, Cr, As and Hg) in the waters of Lake Nangbéto in order to have reliable data that could contribute to a safe use of the lake waters.

MATERIALS AND METHODS

Study area

The Lake Nangbéto, is located about forty kilometers away from Atakpamé, and 160 km away from Lomé (Togo). It has been originated after the building of a dam on the Mono river, and occupies an area of 180 km². The Lake Nangbéto is located at 180 km from the Mono river mouth and is fed by a 15,700 km² catchment area over a total area of 24,000 km^2 covered by the Mono watershed. The Mono watershed is located between the latitudes of 9°20' North at the source and 6°174' North at the mouth in the Gulf of Benin then between the longitudes 0°41' East and 1°45' East (Figure 1 and Table 1). As for the Mono river, it originates in the Sokodé massif, in the central region of Togo near the Benin border in the Alédjo mountains and its length is approximately 528 km. The main tributaries of Lake Nangbéto are Ogou, Atale and Noukpoué, on the left bank and Anié, Yoro, Amou and Chra, on the right bank. The last 100 kilometers at the mouth of the river mark the border between Togo and Benin (UNESCO, 2008).

Water sampling

The water samples were collected on July 27, 2018 and March 22, 2019, the respective dates of the rainy season and the dry season. A total of 42 water samples (21 per season) were collected. The waters were sampled at 25 cm below the surface in polyethylene bottles (1.5 liter) after rinsing with site water. Bottles were previously washed with nitric acid (10%) and then rinsed with distilled water in the laboratory. These samples were labeled and packaged in a cooler containing ice packs. The samples were then sent to the laboratory. In the laboratory, the waters intended for the analysis of trace elements were acidified to 1% with nitric acid for the solubility of the trace elements and to prevent their adsorption. They were filtered with 0.45 µm mesh filters and preserved in the refrigerator at 4°C until analysis (Rodier et al., 2009; Issola et al., 2008; Yao et al., 2009).

Chemical and physical analysis

Water samples are acidified to 1% with concentrated nitric acid (HNO_3), filtered through a filter (0.45 µm), and stored at room temperature until analysis (Tay et al., 2009; El Morhit et al., 2009). The trace elements (Cd, Pb, As, Cu, Cr, and Ni) were determined by AAS flame type analyzed, STATISTICA version software were used for processing the data. Thus, a principal component analysis (PCA) was carried out in order to highlight the relationships between the physico-chemical parameters of water; between the

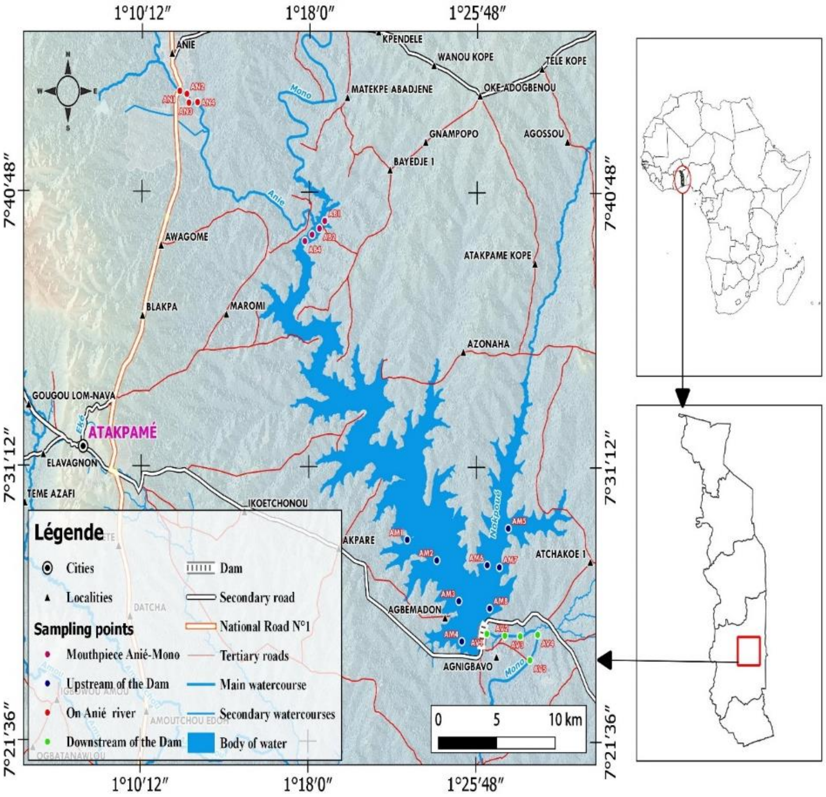

Figure 1. Map of the Lake Nangbéto area showing the water sampling sites.

Table 1. Sampling sites coordinates.

Samples	Latitudes	Longitudes
AV1	07°25’29.6’’	001°26’09’’
AV2	07°25’26.8’’	001°26’15.3’’
AV3	07°25’27.1’’	001°26’23.1’’
AV4	07°25’21.05’’	001°26’37,0’’
AM1	07°26’15.8’’	001°26’26.0’’
AM2	07°27’42.2’’	001°26’52.9’’
AM3	07°29’02.5’’	001°27’45.1’’
AM4	07°28’32.5’’	001°26’37.3’’
AM5	07°27’46.6’’	001°26’18.7’’
AM6	07°27’08.2’’	001°25’59.5’’
AM7	07°26’25.0’’	001°24’49.5’’
AM8	07°26’22.4’’	001°25’06.5’’
AM9	07°26’02.8’’	001°25’19.0’’
EB1	07°39’48.4’’	001°18’38.9’’
EB2	07°39’47.0	001°18’39.5’’
EB3	07°39’45.7	001°18’40.2’’
EB4	07°39’43.5	001°18’40’5’’
AN1	07°44’18.0’’	001°12’052
AN2	07°44’18.7’’	001°11’991
AN3	07°44’17.5’’	001°12’0 48
AN4	07°44’12.02’’	001°12’199

Thermo Electron Corporation, series AA Spectrometer; by a generator of hydride and cold vapor coupled to Spectrometry flame for As and without flame for Hg. For the physico-chemical parameters, they were determined according standard methods (Rodier et al., 2009; AFNOR, 2001). Conductivity, pH, and temperature were detected *in-situ* using a Knick Portamess conductivity meter and Crisson pH meter (Rejsek, 2002).

Expression of the results

The pollution factor (PF) is used to express the level of contamination of trace elements in water samples in comparison to WHO standards.

$$PF = \frac{\text{(Concentration of the element in water)}}{\text{(WHO standard of the element)}}$$

PF ≥ 1, there is pollution; PF≤1, there is no pollution.

Statistical analyses

For processing the results of the various parameters

Table 2. Seasonal data for the contents of the element in water.

Statistical parameters	Trace elements (µg/L)						
	Cd	Pb	Ni	Cu	Cr	As	Hg
Rainy season (n = 21)							
Minimum	7.85	4.8	0.04	2.3	<DL	0.49	1.09
Maximum	10.11	37.5	5.68	13.7	<DL	5.14	3.65
Averages	9.21	14.38	2.36	7.02	<DL	2.31	2.33
SD	0.70	12.13	2.12	4.73	<DL	0.96	0.97
CV(%)	7.63	84.34	89.76	67.35	<DL	41.67	41.76
Dry season (n = 21)							
Minimum	5	4	<DL	3.5	<DL	3.13	5.70
Maximum	10.3	94.3	<DL	34.7	<DL	9.08	9.57
Averages	6.8	42.53	<DL	13.25	<DL	4.37	8.04
SD	3.03	22.33	<DL	9.33	<DL	1.42	1.33
CV(%)	44.58	52.49	<DL	70.47	<DL	32.55	16.55
Test t (p)	0.0483	0.0006		0.1852		0.0015	0.0000
WHO standards	3	10	70	2000	50	10	6

n, Number of samples; **CV,** Coefficient of variation; **SD,** Standard deviation; **DL,** detection limit.

concentrations of trace elements in water on the one hand, and on the other hand between the different sampling sites (Tessier and Bonté, 2002; Liu et al., 2003; Probst et al., 2009; Kaiser, 1961). The Student's t test at the 5% threshold was used to compare the seasonal variability of concentrations of trace elements in water and with the water quality standard. The Pearson correlation was used in order to know the correlations among the different trace elements and the physico-chemical parameters on the one. Average concentrations of trace elements were compared against WHO standards.

RESULTS

Concentrations of trace elements in water and their comparison with the WHO standards for drinking water

Seasonal and spatial concentrations of trace elements in water

The values of the concentrations of trace elements in water for the different seasons are presented in Table 2. The statistical analysis of trace elements concentrations in seasonal water (Table 2) show that the cadmium average value in rainy season is higher than dry season (9.21 ± 0.7 µg/L and 6.8 ± 3.03 µg/L). Figure 2 shows the spatial and temporal distribution of the Cd concentrations in the water. In the rainy season, Cd was detected only in the upstream (EB1-EB4) and Anié sites (AN1-AN4). In the dry season, Cd was only detected in three (3) sites of Anié river have levels above the detection threshold of the device used, which is 0.001 mg/l.

The average value of lead (Pb) in the dry season (42.52 ± 22.33 µg/L) is higher than rainy season (14.32 ± 12.13 µg/L). The spatial distribution (Figure 3) shows that lead concentrations in the dry season, most of the sites recorded Pb concentrations above the detection limit. These concentrations are all higher than those of the rainy season. The highest concentrations in the rainy season are found in the waters from Anié and upstream.

The values of nickel (Ni) contents vary from 0.04 to 5.68 µg/L in the rainy season with an average value of 2.36 ± 2.12 µg/L. In the dry season, the Ni contents of the water at all the sites were below the detection limit which is 0.009 mg/L. Figure 4 shows that only the upstream and Anié sites contained concentrations above the detection limit, while those from upstream and downstream had concentrations below the detection limit.

The copper (Cu) average value in the dry season (13.25 ± 9.33 µg/L) is higher than rainy season (7.02 ± 4.73 µg/L). Figure 5 shows that in the rainy season only few sites from downstream and upstream have Cu contents above the detection limit. In the rainy season, only the mouth and Anié sites have concentrations above the detection limit. The others have concentration below the detection limit.

The Chromium (Cr) contents of the water in all seasons and at all sites are below the detection limit. The Arsenic (As) concentration vary from 0.49 to 5.14 in the rainy season with an average of 2.31 ± 0.96 µg/L. Those of the dry season vary from 3.13 to 9.08 µg/L with an average of 4.37 ± 1.42 µg/L. Figure 6 highlights the superiority of As concentrations in the dry season compared to those in the rainy season.

The mercury average concentrations in the dry season

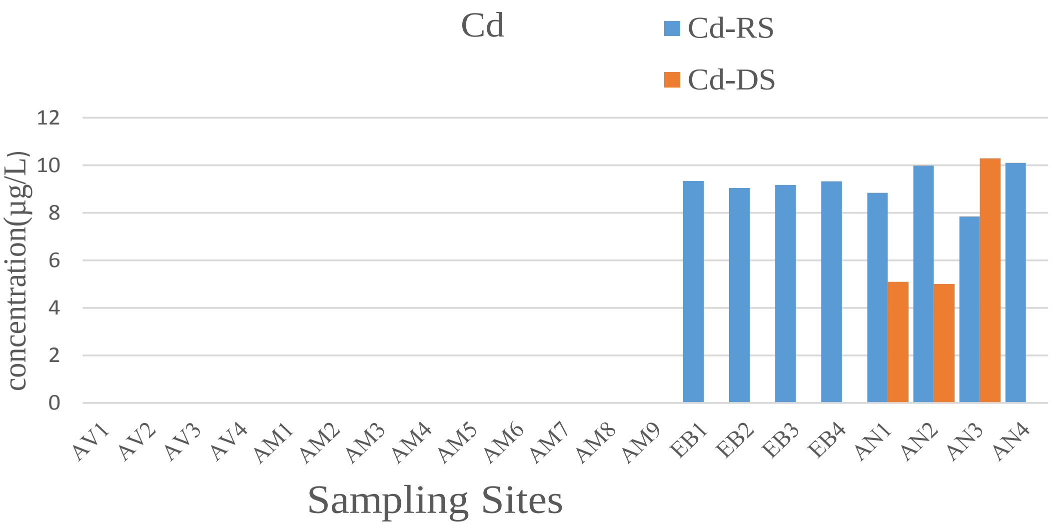

Figure 2. Seasonal and spatial cadmium (Cd) concentrations of the water.

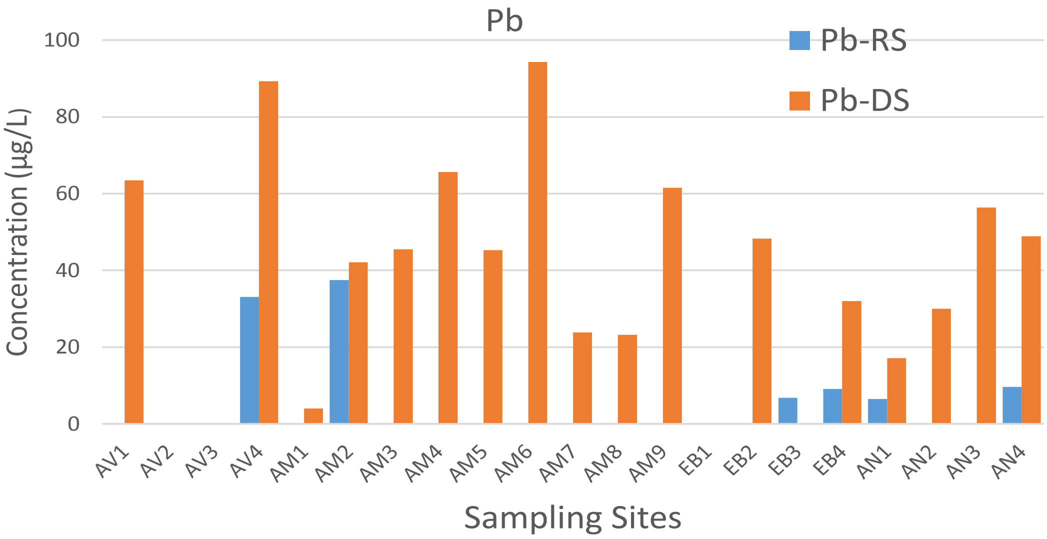

Figure 3. Seasonal and spatial lead concentration of the water.

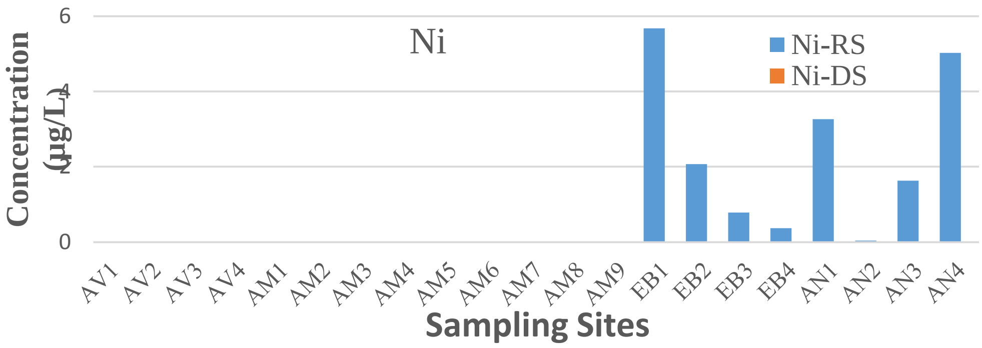

Figure 4. Seasonal and spatial nickel contents of the water.

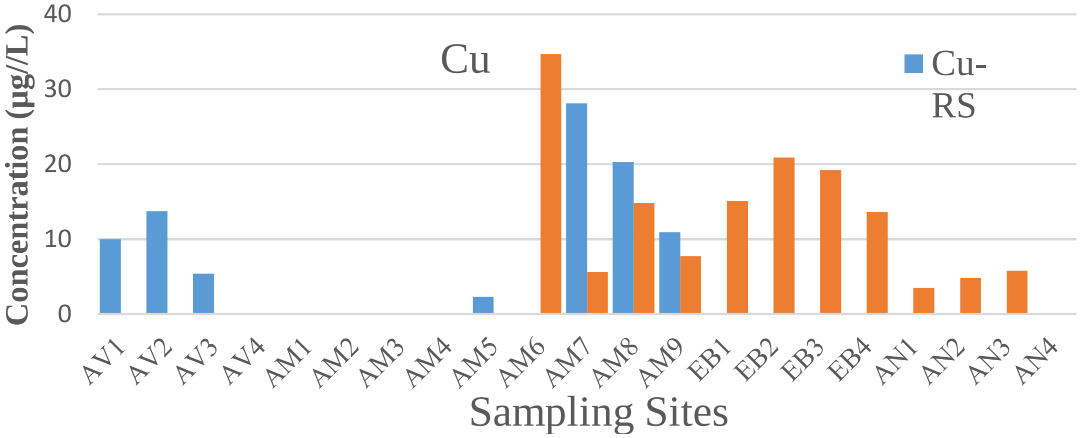

Figure 5. Seasonal and spatial copper contents of the water.

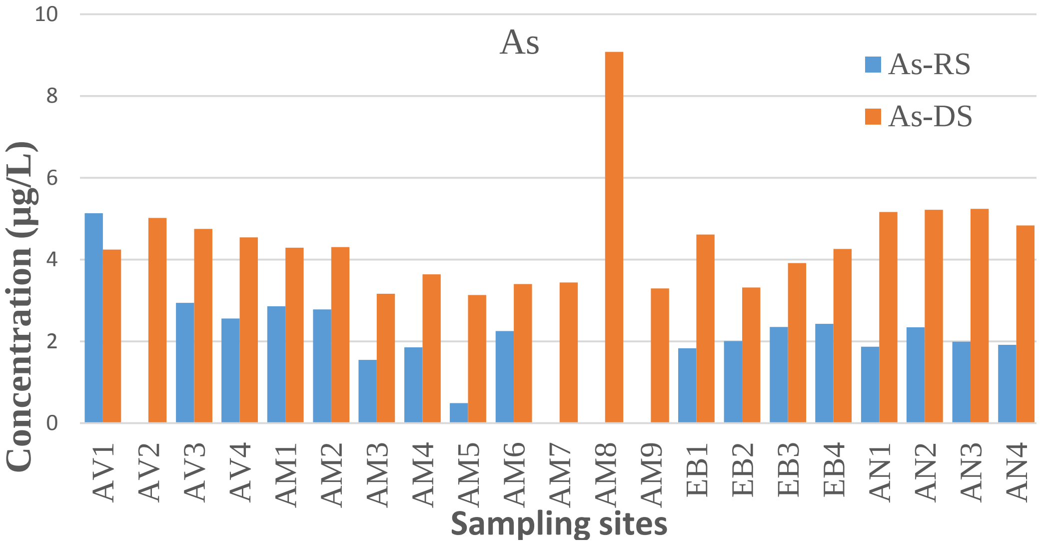

Figure 6. Seasonal and spatial As contents of the water.

(8.04 ± 1.33 µg/L) is higher than rainy season (2.33 ± 0.97 µg/L). Figure 7 shows the Hg concentration of the dry season much higher than those of the rainy season. While the highest values are observed downstream and upstream in the rainy season, the upstream and Anié zone record low concentrations. In the dry season, the contents are the same in all areas except some upstream sites which show a lower concentration.

Assessment of the potability of the water sampled via pollution factors of the trace elements considered

The pollution factors assessment is present in Table 3 and Figure 8. Table 3, Figures 8 and 9 show that the average cadmium contents of the waters of Lake Nangbéto are higher than the content recommended by WHO for drinking water both in the rainy season and in the dry season with respective pollution factors of 3.07 and 2.27 (Table 3). The lead concentrations are also higher than the WHO standard in the rainy and dry seasons (Figures 8 and 9). The pollution factors are 1.44 times the WHO standard for the dry season and 4.25 times for the dry season (Table 3).

The concentrations of Ni, Cu and As in both the rainy and dry seasons are lower than their respective standards set by the WHO for drinking water for these elements. Their pollution factors are respectively 0.03; 0.004 and 0.23 in the rainy season and 0.00; 0.007 and 0.44 in the dry season. The results showed that the Cr contents were

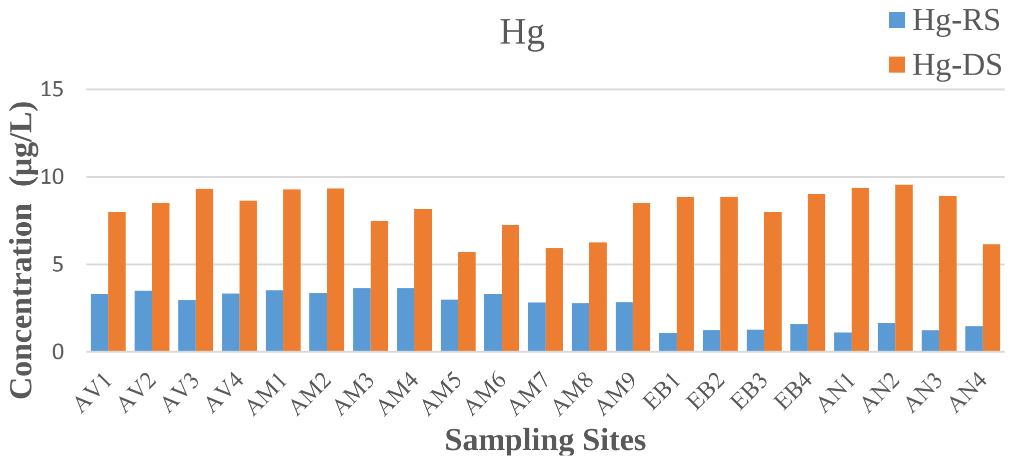

Figure 7. Seasonal and spatial Hg content in the water sampled from the different sites.

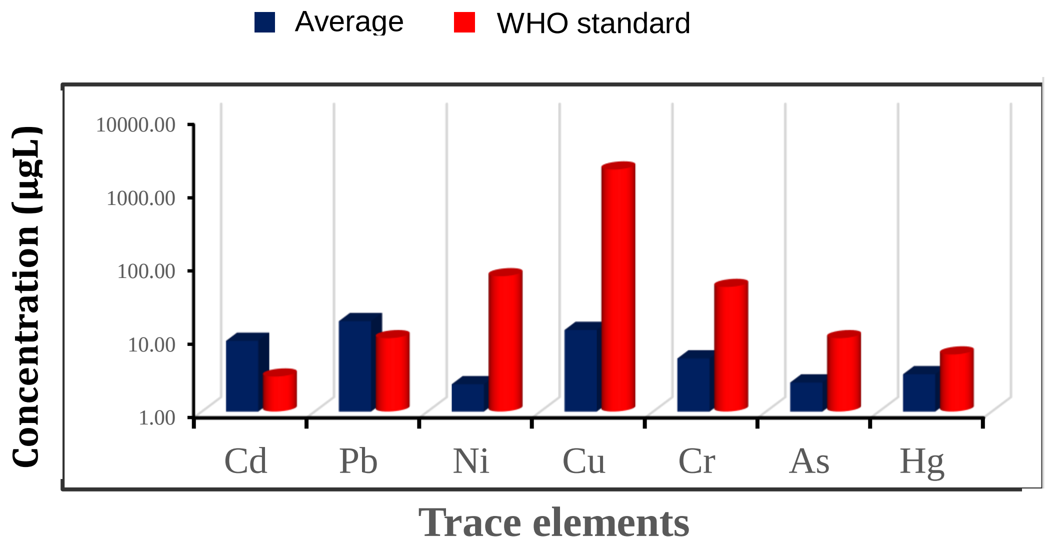

Figure 8. Histogram of the average concentrations of trace elements in water sampled in the rainy season compared to the standard values set by WHO for drinking water.

Table 3. Pollution factors of trace elements studied in water.

Statistical parameters	**Trace elements (µg/L)**						
	Cd	**Pb**	**Ni**	**Cu**	**Cr**	**As**	**Hg**
Rainy season							
Averages	9.21	14.38	2.36	7.02	<DL	2.31	2.33
WHO standards	3	10.00	70.00	2000	50	10	6
pollution factor	**3.07**	**1.44**	**0.03**	**0.004**	-	**0.23**	**0.39**
Dry season							
Averages	6.80	42.53		13.25	<DL	4.37	8.04
WHO standards	3	10	70	2000	50	10.00	6.00
pollution factor	**2.27**	**4.25**	**0.00**	**0.007**	**-**	**0.44**	**1.34**

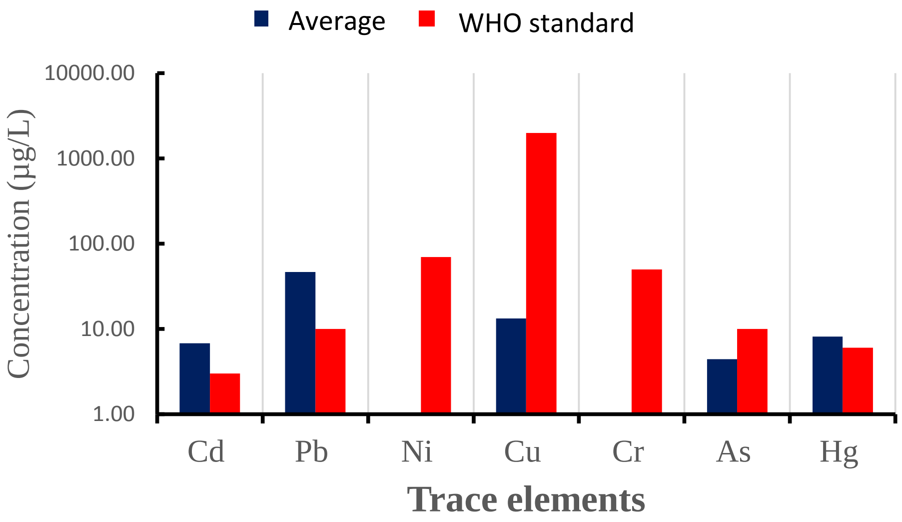

Figure 9. Histogram of the average concentrations of trace elements in water sampled in the dry season compared to the standard values set by WHO for drinking water.

below the detection limit for both seasons. The mercury content is lower than the WHO standard in the rainy season with the pollution factor of 0.39 times. In the dry season this concentration is higher, (1.34 times the WHO standard).

Statistical processing of the results of water contamination

The typological study is carried out by the PCA applied to the seven (7) variables (Cd, Pb, Ni, Cu, Cr, As and Hg), 21 sites (observations or individuals) and some physico-chemical parameters of the water (pH, temperature, conductivity) both in the rainy season and in the dry season.

Analysis of the correlation matrix

The seasonal Pearson correlation of trace elements and some physico-chemical parameters are presented in Table 4. Table 4 presents the Pearson correlation matrix of some physicochemical parameters and the various seasonal trace elements studied. The Pearson correlation applied to the results shows that in the rainy season, the temperature is significantly and negatively correlated with As; pH is significantly and negatively correlated with total dissolved solids (TDS) and Hg; electrical conductivity (EC) positively and significantly correlated with TDS, Pb and Hg; Pb is positively and significantly correlated with Hg; Ni is correlated significantly and negatively with As. In the dry season, the temperature is positively correlated with the TDS; EC is negatively correlated with TDS; As is positively correlated with Hg.

The results of the eigenvalues, percentage of total and cumulative variances expressed in Table 5 from the PCA, show that in the rainy season the first four (4) factors together explained 88.11% of the variance: F1 = 37. 22%; F2 = 21.26%; F3 = 14.09%; F4 = 9.26%; while in the dry season they give 77.970% of the total variance explained including: F1 = 34.54%; F2 = 21.19%; F3 = 11.51%; F4 = 10.72%. The factorial plan (F1 × F2) gives 58.47% in the rainy season and 55.73% in the dry season.

Projection in the F1×F2 plane of the variables rainy season and dry season

The projection of the variables in the factorial plane F1 × F2 is presented by Figure 10. In the rainy season, the axis F1 (37.22%) of Figure 10A is defined positively by the parameters pH, the trace elements Ni and Cd then negatively by the parameters EC and TDS and the elements Cu and Hg. The axis F2 (21.26%) is defined in its positive part by the temperature and in its negative part by the Pb and As. In the dry season (Figure 10B), the F1 axis (34.54%) is defined in its positive part by Cd, Cr, Ni, pH and TDS and in its negative part by EC. The F2 axis (21.19%) is defined in the positive part by the Pb and in its negative part by the Cu and T°C.

Projection in the F1×F2 plane of the sampling sites (individuals or observations)

The projection of the water sampling sites in the factorial plane F1 × F2 (Figure 11) distinguishes two groupings of

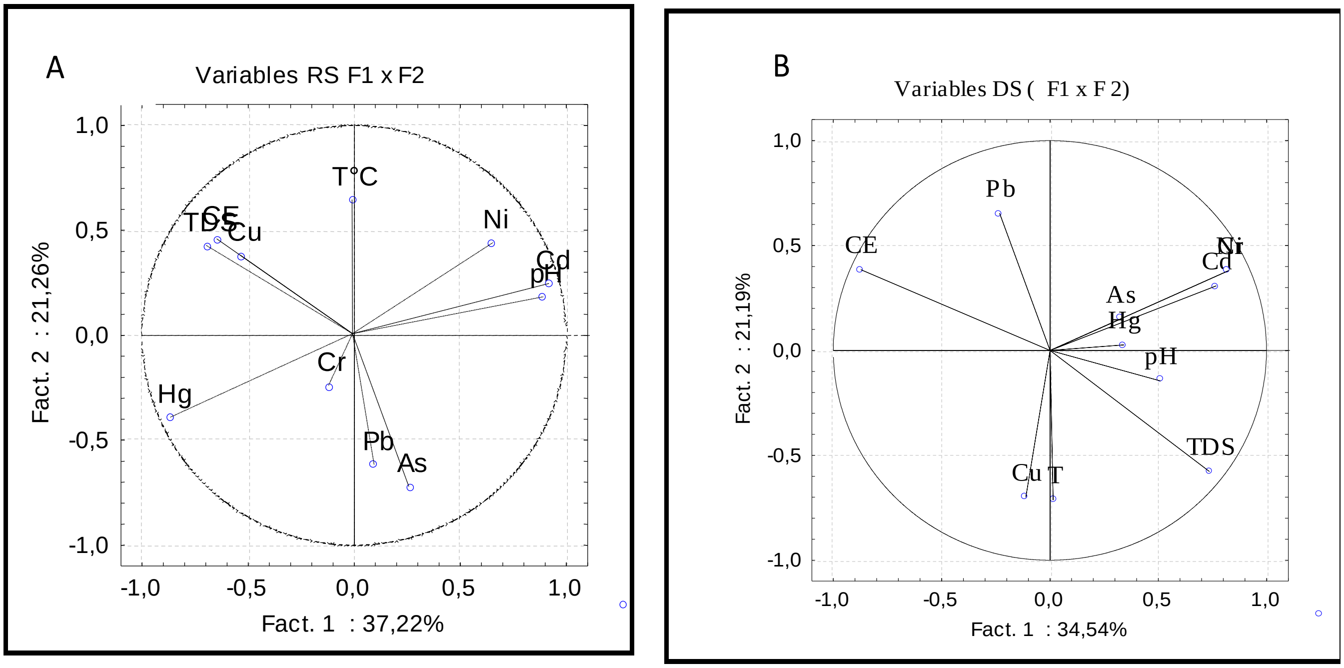

Figure 10. Projection of the variables in the F1 × F1 factorial Plan in the rainy season (A) and in the dry season (B).

Table 4. Seasonal Pearson correlation of trace elements and some physico-chemical parameters.

		RAINY SEASON										
		T	**pH**	**CE**	**TDS**	**Cd**	**Pb**	**Ni**	**Cu**	**Cr**	**As**	**Hg**
DRY SEASON	**T**	1	0.00	-0.06	-0.06	-0.49	-0.06	0.58	-0,97**	-	-0.56*	-0.06
	pH	0.13	1	-0.40	-0.44*	0.07	-0.29	-0.16	-0.20	-	-0.29	-0,73**
	CE	-0,324	-0.40	1	0.99**	-0.01	0.73*	0.35	0.34	-	0.20	0.56**
	TDS	0.46*	0.39	-0.96**	1	0.03	0.78**	0.37	0.20	-	0.15	0.60**
	Cd	0.82	-0.27	-0.81	0.81	1	0.86	0.15	-	-	0.22	0.57
	Pb	0.01	0.12	0.073	-0.14	0.97*	1	0.26	-	-	0.78	0.89**
	Ni							1	-	-	-0.87**	-0.54
	Cu	0.03	-0.15	0.03	-0,22	0.98	0.28	.b	1	-	0.99	0.65
	Cr							-				
	As	0.37	-0.02	-0.10	0.15	0.81	0.02	.b	-0.05	.b	1	0.25
	Hg	0.24	-0.30	-0.41	0.39	0.78	0.31	.b	0.13	.b	0.49*	1

* The correlation is significant at the 0.05 level; ** The correlation is significant at the 0.01 level.

Table 5. Eigenvalues of the percentage of total and cumulative variances.

	Rainy season				**Dry season**			
	F1	**F2**	**F3**	**F4**	**F1**	**F2**	**F3**	**F4**
Eigenvalues	4.09	2.34	1.58	1.03	3.80	2.33	1.26	1.17
% Total variance	37.22	21.26	14.09	9.26	34.54	21.19	11.51	10.72
Owen cumulative value	4.09	6.43	8.02	9.05	3.80	6.13	7.40	8.57
% Cumulative variance	37.22	58.47	72.87	88.11	34.54	55.73	67.25	77.97

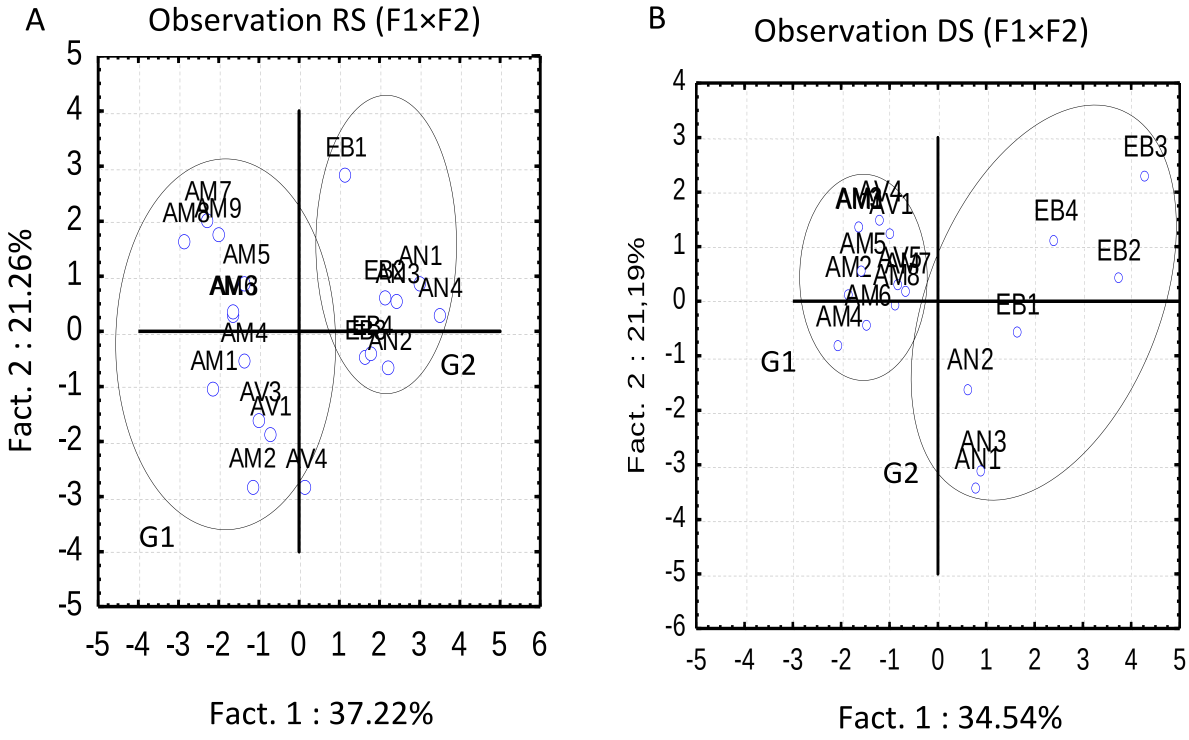

Figure 11. Projection of sites in the factorial plane F1 × F1 in the rainy season (A) and in the dry season (B).

sites showing two types of water in the study area both in the rainy season and in the dry season. The projection of the sites in the rainy season (Figure 11A), presents a first group which includes the sites of the upstream (AM) and downstream (AV) zone of the dam. The waters of this group present a larger load of As, Pb, Cu, and Hg and more mineralized. On the other hand, these waters have less concentrations of Ni, Cd and are more acidic. The second type and group of waters are the sites of Anié (AN) and upstream (EB). The waters of this last group contain high concentration of Ni, Cd and tend towards basicity. These waters show low concentrations of As, Pb, Cu, Hg and low mineralization. In the dry season, the same groups emerge but with differences. The upstream and downstream group show a narrowness in the grouping of sites, thus highlighting the homogeneity of the characteristics of these waters. They are characterized by strong mineralization (high EC) with a high Pb content. The second group of Anié and mouth shows heterogeneity in the characteristics of the waters of the different sites. This heterogeneity is highlighted by the distension between the different sites. Besides the sights of the Mouth stand out from those of Anié during this season. The waters of the mouth are more concentrated in As, Hg, Cd, Ni with tendencies from neutrality to basicity; poor in TDS and Cu. Anié waters show high TDS and high Cu contents but low in As, Hg, Cd, Ni with rather acidic tendencies.

DISCUSSION

The results of the analysis of Cd, Pb, Ni, Cu, Cr, As and Hg in Lake Nangbéto waters show that there is variability between these trace elements concentrations. While some trace elements have higher concentrations than the WHO standards for recommended for drinking water, other trace elements have acceptable concentrations (WHO, 2011). There is also a variability in the contents of the elements according to the seasons and the sampling sites. Three trace elements of the seven studied have concentrations above the WHO recommendations. These trace elements are cadmium (9.21 µg/L in the rainy season with 3.07 times the WHO standard; 6.80 µg/L in the dry season, with 2.27 times), lead (14.38 µg/L rainy season with 1.44 times; 42.53 µg/L in dry season with 4.25 times) both in rainy season and mercury in dry season (8.04 µg/L with 1.34 times the WHO Standard).

The waters of Lake Nangbéto are therefore not fit for human consumption. This conclusion can be nuanced because AAS method used, can test full concentrations of chemical elements, but not only ions, however WHO standards were mainly prescribed for ions. Having no known function in the human body (Miquel, 2001b), cadmium, lead and mercury are the most toxic trace elements for humans (Testud, 2005; Needleman et al., 1990). Among the toxic effects of these elements following prolonged exposure to humans are the kidneys, bone disease, damage many systems in the body (nervous, reproductive and respiratory system).

As for the trace elements Ni, Cu and As, their contents remain lower than their respective standard set by the WHO (70; 2000; 50; 10 µg/L) for drinking water in these elements in all seasons. For Ni, Cu and As, there is therefore no health risk following the consumption of the water of the lake. Their pollution factors are respectively 0.03, 0.004 and 0.23 in the rainy season and 0.00, 0.007, and 0.44 in the dry season. The results showed that the Cr contents were below the detection limit of the meter. Consequently, these contents are considered to be zero (Debieche, 2002). The waters of Lake Nangbéto are therefore drinkable with respect to this metallic element. This result agrees with that of Chaoui (2013) who showed that the lead content of the surface water of the Oued in the vicinity of the abandoned Zeïda mine are below the detection limit of the device used (0.002 mg/L).

Cadmium contamination shows higher average concentrations in the rainy season than in the dry season. This shows the recent nature of pollution by this element. The pollution of cadmium which is of anthropogenic origin via runoff water which collects pollutants from the effluents of the large cities crossed by the Mono River and especially the residues of inputs used in the study area (chemical fertilizers, herbicides, insecticides or fungicides) for agricultural purposes practiced during the rainy season (Laë, 1996; SOTOCO, 2009). The presence of this element only in the sites of Anié and the mouth in the rainy season and in Anié only in the dry season shows that the Anié sugar industry and its vast fields of sugar cane contribute significantly to pollution. Cadmium, lead and mercury, on the other hand, have average levels in the rainy season that are significantly lower than in the dry season. Lead is an old and permanent pollutant because it is a metal widely used since the days of the Romans. Therefore, it is very widespread throughout the environment. Due to its wide distribution, ease of extraction, high malleability and low melting point it is found in all environmental compartments (Greenwood and Earnshaw, 1984). The higher concentrations of lead and mercury in the dry season are explained by the decrease in the water level due to evaporation during this period of strong sunshine and the absence of rains. On the other hand, the relatively low concentrations in the rainy season can be explained by the dilution of the water contents by a lot of rainwater.

The lead and mercury in these waters have the same origins as a preceding element (Cd). In fact the use in the study area of chemical fertilizers, insecticides or fungicides for agricultural purposes in the Mono basin enriches the lake in these elements. Also, the material used, namely the nets whose knots are made of lead, constitute probable sources of water pollution by lead.

By comparing the trace elements contents in the waters of Lake Nangbeto with those of other studies, it appears that the concentrations of traces elements recorded are quite close to those detected in the surface waters of the Bonoua region in the southeast of the Ivory-Coast for Cu (Tohouri et al., 2017). The concentration of trace elements recorded are higher than those obtained in the waters of the Lake Togo-Lagoon of Aného for Hg (Ouro-Sama , 2019) of the same waters varying from 3 to 6 µg/L. On the other hand, the concentrations of trace element recorded in the waters of Lake Nangbeto are lower than those obtained in the waters of the Tislit-Talsint Wadi in eastern Tislit-Talsint Wadi in eastern Morocco for Ni (Taouil et al., 2012), in the waters of Lake Togo-Lagoon of Aného for Cd, Pb, Ni, Cu, Cr and As (Ouro-Sama, 2019).

Conclusion

The present study on the evaluation of contamination by trace elements in the waters of the Lake Nangbéto area revealed the presence of several trace elements at different pollution levels. In general, the waters of the Anié zone and of the Anié and Mono mouths are more contaminated than that of the lake near the Dam. The comparison of the contents of these trace elements with the standard values of the WHO for drinking water revealed that the chromium concentrations are all lower than the detection limit (0.002 mg/L) of the measuring device both in the rainy season and in in the dry season. The seasonal average concentrations of trace elements Ni, Cu and As meet the WHO recommendations for drinking water. However, the waters studied are polluted for all seasons by Cd and Pb and in the dry season by Hg. Thus, the consumption of these waters by the populations and aquatic species exposes them to the risk of poisoning in these last three elements. The results of this study highlight a public health problem for these three elements linked to the consumption of water from Lake Nangbéto and its surroundings. These waters need sanitation and treatment before consumption.

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