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South-West Benin Coastal Lagoon: Waters and sediments' toxicity and contents in heavy metals during high water period (Togbin to the Mono Mouth)

O. B. M. Lucinde BOCODAHO[1,3*], Waris Kéwouyèmi CHOUTI[1,2], R. Arthur CAKPO[2] and Daouda MAMA[1,2]

[1]*Laboratory of Applied Hydrology, National Institute of Water (NIW), University of Abomey-Calavi (UAC), 01 PO: 526 Cotonou, Benin.*
[2]*Laboratory of Inorganic Chemistry and Environmental, Faculty of Sciences and Technologies (FAST), University of Abomey-Calavi, Benin (UAC), PO: 4521 Cotonou, Benin.*
[3]*International Chair in Mathematical Physics and Applications (ICMPA-UNESCO CHAIR), University of Abomey-Calavi (UAC), 072 PO: 50 Cotonou, Benin.*
[*] *Corresponding author; E-mail: bokomarthe@yahoo.com ; Tel.: +229 96 13 01 84*

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ABSTRACT

The uncontrollable population growth is reaching Benin's rivers, especially the coastal lagoon, raising then the thorny problem of pollution, which is considerably accentuated by the malevolent behavior of the populations. The aim of this paper is to characterize the degree of contamination of the water and sediments of the lagoon in heavy metals (Cd, Cr, Zn, Cu, Pb and Fe) through the dosage with the molecular absorption spectrophotometer type DR 3900. At the same time, a cytotoxicity test with *Allium cepa* will be carried out in order to evaluate the toxic potential of the pollutants responsible for the degradation of the lagoon. The Cd, Cu and Zn contents in the water and sediments far exceed the accepted standards at almost all the stations. The Pollution Index (PI) and geo-accumulation index (Igeo) indicate the existence of polymetallic pollution in the sediments, which is extremely strong and dominated in order to decrease abundance by: Cd>Zn>Cu>Pb. The results of the cytotoxicity test highlight acute toxicity on 82% of the stations surveyed. The poor states of the coastal lagoon indexed by this study, impose the application of urgent measures of participative management, preservation and sanitation of the coastal zone.
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Keywords: Coastal Lagoon, polymetallic pollution, cytotoxicity, geo-accumulation, Allium cepa.

INTRODUCTION

Water is an essential resource for all life on earth. Unfortunately, this precious commodity is continually threatened by all forms of pollution, which is becoming increasingly important (Youssao et al., 2011). In fact, in all West African countries, and more particularly in Benin, water bodies have become receptacles for waste of all kinds, especially in these regions where adequate management of household waste and wastewater remains a major challenge (Traoré et al., 2012; Adjagodo et al., 2016). Most of these solid, liquid and valve wastes, which are

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linked in particular to human activities, industrialization and urbanization, are loaded with organic matter and highly toxic non-biodegradable heavy metals and cause degradation in water bodies while affecting negatively the biotope. However, of all the forms of pollution, metal pollution seems very dangerous and disrupts the natural balance of aquatic ecosystems in the long term (Katemo et al., 2010).

The coastal lagoon of Southwest Benin, notwithstanding the tourist, socio-cultural and economic assets conferred by its rich fauna and flora, is hardly exempt from this sad reality ((NT-ONG, 2006) and (Chouti et al., 2017a). Considering the prominent place occupied by lagoons among the water bodies, several stakeholders from the scientific world have taken an interest in the quality of water and sediments in the lagoons of the sub-region, especially those of Benin. Some authors assessed the heavy metals in the sediments of Porto-Novo lagoon (Benin) and concluded that the sediments of the said lagoon are polluted with chromium, cadmium and mercury (Chouti et al., 2010). Similarly, Chouti et al. (2017a), studied the waters and sediments of the coastal lagoon (South Benin) and showed that this lagoon is polluted by heavy metals, namely copper and zinc.

The little research carried out on the chemical aspect of the coastal lagoon has remained generally synthetic or even limited, especially in relation to polymetallic contamination. In order to deepen these studies through a research with a much broader spectrum, this study focused more on assessing the degree of toxicity of heavy metals (Fe, Cr, Cu, Zn, Pb and Cd) in the waters and sediments of the lagoon in order to characterize better its state of pollution by metals.

MATERIALS AND METHODS

Study environment

The coastal lagoon which is the subject of this study, is one of the most attractive in the sub-region because of its ecotourism aspect. Located in the southwest of Benin, the lagoon environment is part of the 1017 complex and covers the lagoon of Grand-Popo and that of Ouidah (Houéto, 2013). Also known as Djessin, it extends over an area of 55 km^2 from the mouth of the Mono at Akouèta in the West to Togbin in the East of Cotonou. The coastal lagoon is completed by the Gangban channel and is fed by three main rivers, Couffo, Mono and Sazué (Fiogbé et al., 2007). The main anthropogenic activities carried out in the lagoon complex are dominated by agriculture, fishing and animal husbandry. Its maximum depth varies between 0.40 m to 1.70 m in low waters and between 1.10 m to 3.40 m in high waters (Guillard et al., 1982; PGPE, 2008).

Sampling

In order to assess heavy metals contamination within the coastal lagoon during high water periods, eleven (11) water and superficial sediment samples were collected from the lagoon bed. The sampling stations were defined approximately in relation to the discharges, the neighboring towns, the presence of latrines and according to the hydrological and environmental contexts of the lagoon environment. After the *in situ* measurements, water samples were taken a few centimeters from the surface of the water in 1.5 L plastic bottles and in 25 L drums for the determination of heavy metals and cytotoxicity test respectively. The sediment samples were collected between 0 and 5 cm using a linoleum bin and were kept in aluminum foil to protect them from light. Water samples are kept cool in a portable ice chest on the way to the laboratory. Table 1 shows the different sampling stations with their specific criteria.

Physico-chemical parameters

The physico-chemical parameters that influence the behavior of the heavy metals in the aquatic environment were determined by *in situ* measurements using the multi-parameter conductivity meter (temperature, depth, redox potential) and the pH meter (pH) type WTW 3630 IDS. The geo-referencing of the sites is carried out by a GPS of the GARMIN type. At each station, the probe is rinsed with distilled water and then the water is to be sampled before any measurement. The cytotoxicity test was carried out at the Inorganic Chemistry and Environment Laboratory (LACIE) of the Faculty of Science and Technology of the

University of Abomey-Calavi. As for the determination of heavy metals in water and sediments, it was realized at the Laboratory of the National Public Health Directorate (DNSP/Cotonou). Figure 1 illustrates the distribution of sampling points along the coastal lagoon.

Cytotoxicity test on *Allium Cepa*

The toxicity of the lagoon waters was evaluated by the *Allium cepa* test taking into consideration the root elongation inhibition parameter to determine the efficient concentration CE_{50}. The synthetic environment based on the method of Rank and Nielsen (1997) was used as a control to assess the degree of toxicity. To carry out the test, five different dilution percentages were assigned to the samples through well-defined concentrations in which the root base of onions was introduced. The dilution concentrations for sowing were divided into 0%, 25%, 50%, 75% and 100% at the rate of five (5) tests per percentage concentration per sample. The 0% dilutions correspond to a concentration of 100% of the synthetic environment and the 100% represents only the water in the lagoon. The intermediate dilution concentrations of 25%, 50%, and 75% between the 0% and 100% concentrations correspond to the proportional mixing of the control with the lagoon water samples. For this test, 275 onion bulbs with a diameter varying between 5 and 8 cm were used. The 275 onion bulbs, without their outer layer and roots, were placed on 275 glass jars containing the previously diluted solutions, so that the base of the main root was immersed in the solution. Incubation was carried out in the dark for 48 hours while rigorously respecting the concentrations of the predefined dilution percentages at each renewal of the solutions every 24 hours. At the end of the 48 hours of exposure, the length of each of the onion roots put in culture was measured by the glass jar. The root growth observed at each station is compared to that of the synthetic medium percentage by percentage. Samples showing inhibition of root elongation compared to the control mainly in proportions 75% and 100% indicate acute toxicity.

Heavy metals dosage

The HACH LANGE DR 3900 spectrophotometer methodology was adopted.

In the waters

The waters are subjected to preliminary treatment (mineralization and neutralization of the mineralization product) before being analyzed. Mineralization was based on the HACH method and the assay was performed using the molecular absorption spectrophotometer (DR 3900) by comparing the reagent-free sample with the reagent-containing sample. Lead and cadmium were determined using the Dithizone method.

In the sediments

The sediment samples, previously dried in an oven at 105°C and finely ground in a mortar, were dissolved with the DR 3900 molecular absorption spectrophotometer for the determination of Cd, Zn, Pb, Cr, and Cu. Copper was determined by the Bicinchronínate method, lead and cadmium, by the Dithizone method and zinc, by the Zincover method.

Processing of results and evaluation of pollution indices

Microsoft Excel 2013 software was used to process the data in an objective analysis of correlation between the variables. The realization of the spatial repair map of the sampling points was possible thanks to the Arc-Gis software.

The diagnosis of metallic contamination in the sediments focused on the determination of the geo-accumulation index (Igeo) and the contamination indices (CI). The geo-accumulation index was initiated by Müller (1981) and makes it possible to evaluate the level of metallic pollution of a sediment in relation to the geological bottom.

$$\mathbf{Igeo} = \mathbf{\log 2} \frac{\mathbf{Cx}}{\mathbf{1,5 * Fgx}}$$

Where $\mathbf{C_x}$ stands for the concentration of the heavy metal concerned in the sediment; $\mathbf{Fg_x}$ stands for the concentration of the trace metal element concerned in a reference geochemical background; the correction factor of 1.5 considerably minimizes the effect of possible lithological fluctuations in the sediments. A scale of six (6) classes was defined on the basis of the values obtained for Igeo. The concentrations of heavy metals in the upper continental crust were taken as reference (Wedepohl, 1995).

The Contamination Index (IC) was used to assess the degree of pollution at each station and throughout the lagoon. It is the ratio between the value considered normal and the one observed in the sediment.

$$\mathrm{IC} = \frac{\text{Concentration found in the sediment (mg/kg)}}{\text{Concentration considered as standard (mg/kg)}}$$

IC is translated into three classes according to the Agence du Bassin du Rhône (1990). At the same time, the pollution index (IP) was evaluated by averaging the ratios between the concentrations of heavy metals observed in the sediments and the standards. The PI not only provides information on the polymetallic contamination of the sediments at a given site but also reflects an increase in the toxicity of the heavy metals in the aquatic environment. A pollution Index greater than 1, corresponds to a soil polluted by several metals (Chon et al., 1998).

Table 1: Water and sediments sampling sites per selection motif.

Designation	Sites	Motifs	Coordinates (UTM)
S1	Togbin	Houses, schools, hotel complexes upstream and downstream of the lagoon	423416 702320
S2	Hyo	Discharge point for household solid waste on both sides of the lagoon	416937 701593
S3	Vodounto	Sacred site reserved for the occult rituals of endogenous religions.	414844 701689
S4	Avlékété	Lagoon-side latrines, solid and liquid waste from concessions and hospitals	412203 701608
S5	Aguoin	Villages on the shore and net fishing practice	408484 700842
S6	Djègbadji	Place of artisanal salt extraction and presence of runoff water collector	399072 699932
S7	Azizakouè	Pig farming area, landfill for household solid waste and domestic sewage; installation of latrines at the edge of the lagoon	392918 699061
S8	Dondji	Very accentuated coastal erosion and opening of the lagoon on the Aho Channel with the inflow of water from Ahémé Lake.	386919 697647
S9	Bouche du Roi	Point of exchange between the Atlantic Ocean and the fluvio-lagunar complexes: crossroads of the hydrological phenomena which govern the whole aquatic ecosystem of the Couffo-lake Ahémé-channel Aho-coastal lagoon.	381641 696342
S10	Avlo	Two villages face to face on the bank separated by the lagoon	377930 695844
S11	Mono Entry	Mouth of the lagoon and the Mono river	372808 694914

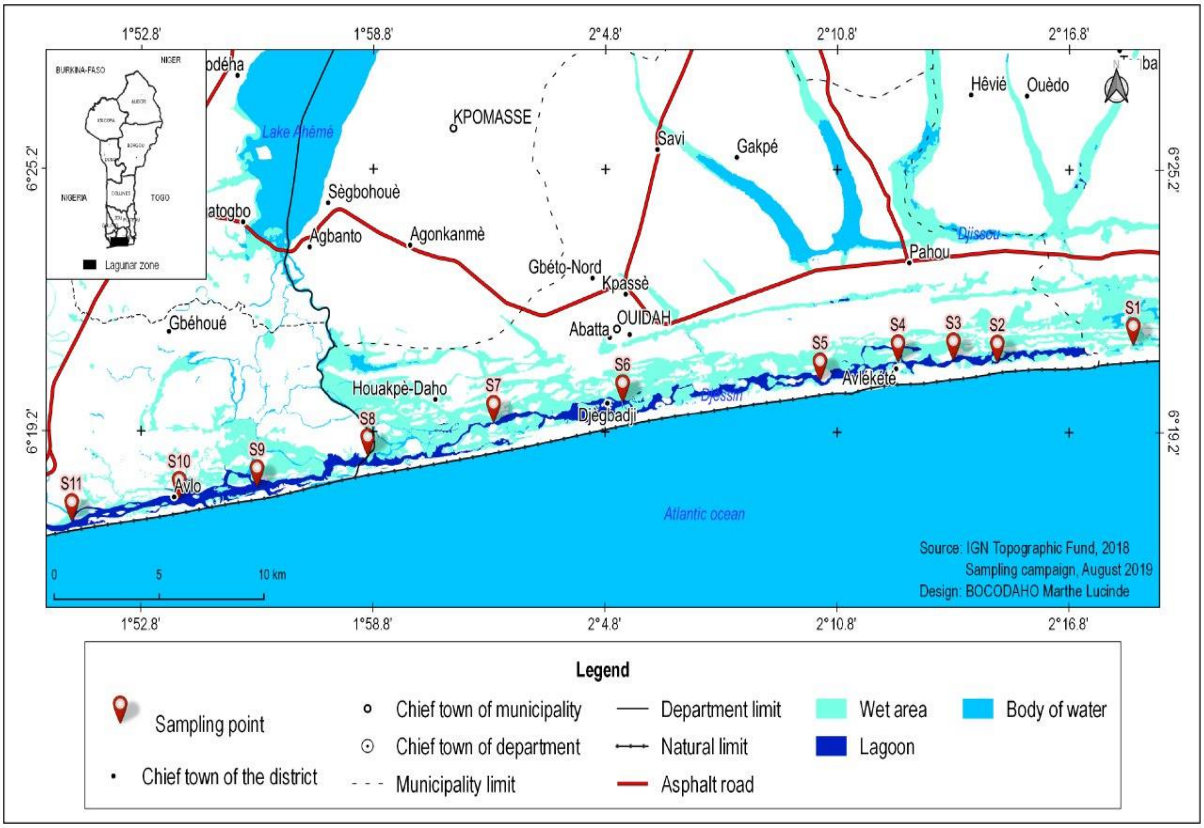

Figure 1: Distribution of sampling points along the Coastal Lagoon.

RESULTS

Physico-chemical parameters of water

Figure 2 illustrates the measurements of the physico-chemical parameters influencing the distribution of heavy metals. Water temperature is involved in almost all physical, chemical and biological reactions. In the waters of the lagoon, a variation of 27.3 to 29.5 °C was observed for the temperature depending on the stations. The highest temperature was observed at station S1, and the lowest at station S9 with an average of about 28 °C. As for pH, it is a factor that increases the solubility of heavy metals. The pH values, ranging from 7.85 (S10) to 7.55 (S9) indicate that the lagoon waters are slightly basic. The Oxidation-Reduction Potential shows negative values over all sampled points and varies between -62.1 and -44.9 with very little significant variation. The highest value was obtained at station S10 and the lowest at station S9. The depth in the coastal lagoon during high water increases from 0.8 to 2.65 m. The lagoon appears to be deeper at station S10 and shallow at station S1.

Waters metallic contamination.

In most samples, the results of the heavy metals contents assays show the presence of Fe, Cu, Cd, Pb, Cr and Zn exceeding the WHO (2011) guidelines for water quality and Canadian standards. Recorded Cu, Pb and Cd values are all above standards in all the eleven water samples analyzed (Figures: 3c; 3e; 3f). For Zn and Fe, grades are above standards on 9 stations with the exception for stations S2 and S4 (Figures 3a and 3b). Chromium levels fluctuate between 0.01 mg/L at station S6 and 0.46 mg/L at station S4. With the exception for station S6, which shows a level (0.01 mg/L) below the standards (0.05 m/L), all the remaining stations (91%) show very high chromium levels (Figure 3d).

A comparison of heavy metals concentrations in water with the surface water quality criteria for the protection of aquatic life (MDDELCC, 2015) shows that at all stations, the concentrations of Zn, Cu, Pb and Cd significantly exceed the criteria for both chronic (CVAC) and acute effects (CVAA). Chromium only approaches the limit at station S6 for CVAC and CVAA. On the other hand, all of the remaining ten (10) stations show values above CVAC and CVAA. Iron shows elevated levels relative to CVAC at all stations including stations S10 and S11. However, on stations S1, S2, S3, S4, S5, S6 and S7, Fe grades remained below the CVAA except on stations S9, S10, S11 where grades are above the CAAC. At station S8, the Fe grade is slightly at the limit of the CVAA.

Metallic contamination of sediments

Figure 4 shows the spatial variation of the concentrations of heavy metals (Zn, Cu, Cd, Pb and Cr) in the sediments in relation to the thresholds over all the sampling stations. In sediments, analyses report concentrations far above the World Health Organization (WHO) sediment quality guidelines at almost all stations for Zn, Cu, Cd and Pb. The exception is about Cr with concentrations far below the threshold value for minor effects. The concentrations obtained for Cu at all stations give a maximum value of 149.987 $mg.kg^{-1}$ with a mean value of 94.28 $mg.kg^{-1}$. For Zn, the maximum concentration was as high as 1825 $mg.kg^{-1}$ at station S1, and 846 $mg.kg^{-1}$ at station S5. Cr had a maximum concentration of 20 $mg.kg^{-1}$ at station S1 and a minimum of 8.8 $mg.kg^{-1}$ at station S11. As for Cd, the maximum value of 8.6 $mg.kg^{-1}$ is obtained at station S9. And as for Pb, it comes out with a maximum of 63.2 $mg.kg^{-1}$ at station S7 and a minimum of 32.4 $mg.kg^{-1}$ at station S5.

Table 5 presents the different indices of geoaccumulation and contamination of the lagoon sediments according to the eleven (11) stations. Following the Igeo indices results, Cd and Zn have the same trends over the majority of stations, with values above 4 and 5 for Cd and values between 3 and 5 for Zn. The sediments of the coastal lagoon then tend towards strong or even extreme pollution for Zn and Cd. Concerning Cu and Pb, the Igeo indices waver between 0.35 and 2.80 for all stations; the sediments are therefore moderately contaminated by Pb and Cu at all stations. Unlike other heavy metals, Cr exhibits negative Igeo index values at all stations, indicating an absence of chromium contamination of sediments.

Regarding the contamination indices (IC), the values [3.28 to 9.57] obtained underline a significant pollution of all the stations by Cd as opposed to Cr, whose IC indices are negligible and far below 3 at all stations. Pb directly follows Cr with relatively low IC indices at all stations. The sediments of the coastal lagoon are not polluted by Cr but slightly affected by Pb. The IC indices in Zn are above 10 for stations S1 and S6, and between [3 and 9] for the other 9 stations. Stations S1 and S6 have sediments heavily polluted by Zn while sediments at stations S2, S3, S4, S5, S7, S8, S9, S10 and S11 are moderately polluted by Zn. In total, 82% of the samples are in the Zn-polluted class and 18% are already in the risk zone. Cu is characterized by a contamination index below 3 but not negligible at stations S3, S4, S8 and S11 as it is relatively close to the limit. However, at stations S1, S2, S5, S6, S7, S9 and S10 the IC indices are above 3 with 64% of sites contaminated by Cu.

Cr and Pb, as opposed to Zn, Cu and Cd revealed contamination indices below 3 on all stations. This classifies the lagoon to the normal class for lead and chromium. Ultimately, it follows that the coastal lagoon is highly polluted with Cu, Cd, and Zn at all stations in general and more specifically at station S1 and S6. The lagoon is classified as a normal area for chromium and lead.

The sum of the contamination indices was used to determine the pollution index (PI):

$$\mathrm{IP} = [\frac{\mathrm{Zinc}}{150} + \frac{\mathrm{Copper}}{28} + \frac{\mathrm{Chromium}}{55} + \frac{\mathrm{Cadmium}}{0{,}9} + \frac{\mathrm{Lead}}{42}]$$

IP = 3.70 far above 1. The lagoon is then subject to a polymetallic pollution.
Figure 5 shows, on the one hand, the inhibition of root lengths as a function of dilution concentrations and, on the other hand, the dose-lethal response. High positive and moderate correlations were observed between Zn, Fe, Cd and root length inhibition of onions indexing their likely common sources from anthropogenic activities.

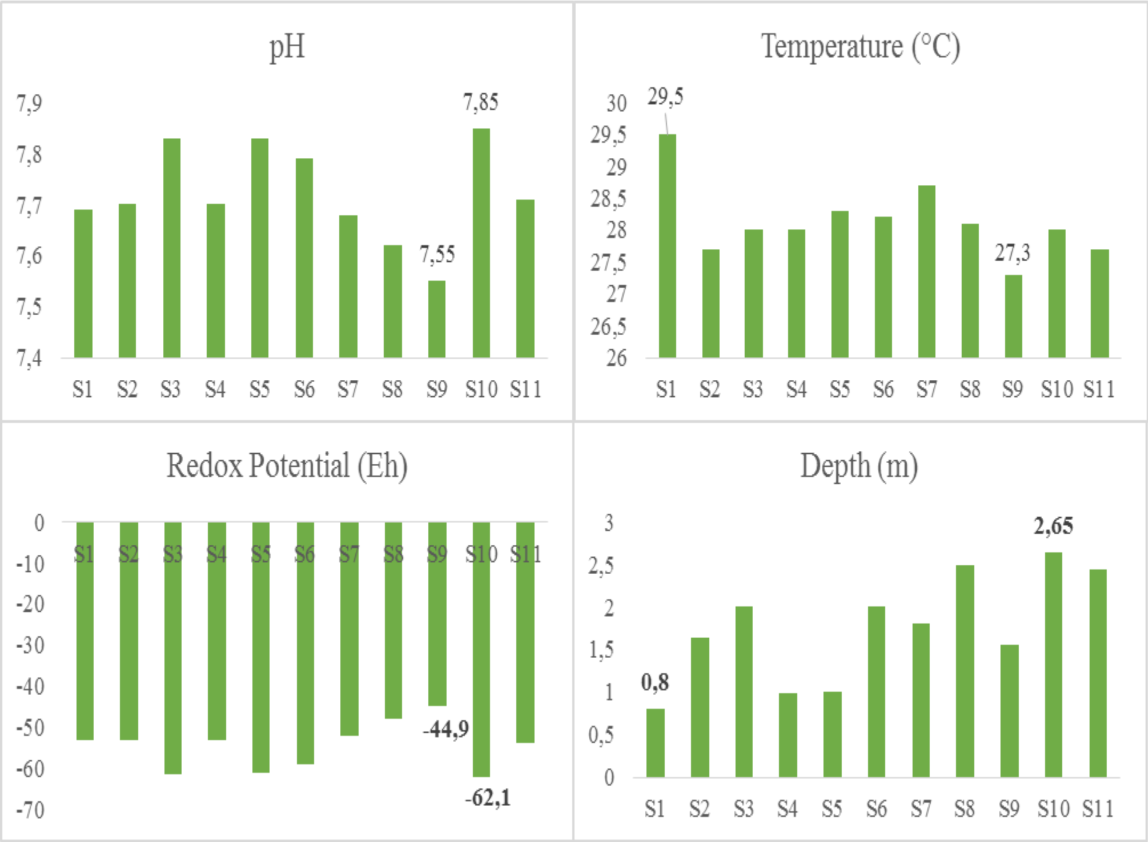

Figure 2: Spatial variation of the physico-chemical parameters (pH, redox potential, temperature and depth) of the Coastal Lagoon waters.

Table 2: Evaluation of metallic contamination of sediments from the Igeo (Müller, 1981).

Class	Value	Sediment degree of pollution
1	**0 ≤ Igeo < 1**	No pollution to medium pollution
2	**1≤ Igeo < 2**	Medium pollution
3	**2 ≤ Igeo < 3**	Medium pollution to high level pollution
4	**3 ≤ Igeo < 4**	High level pollution
5	**4 ≤ Igeo < 5**	High level pollution to extreme pollution
6	**5 ≤ Igeo**	Extreme pollution

Table 3: Classification of water quality according to pollution indices.

Class	Value	Pollution state
1	**CI< 3**	Normal area
2	**3 ≤ CI< 10**	Polluted area
3	**10 ≤ CI**	High risk area

Table 4: Sediments geo-accumulation and contamination indices.

Variables	Index	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Average
Cu	Igeo	2,32	2,33	1,89	1,60	2,13	2,50	2,33	0,78	2,80	1,89	2,13	**2,06**
	Ic	3,84	3,85	2,80	2,33	3,35	4,34	4,34	1,31	5,35	2,84	3,35	**3,43**
Zn	Igeo	4,55	3,57	3,73	3,49	2,91	3,97	3,19	2,93	3,02	3,51	3,18	**3,46**
	Ic	12,17	8,93	9,95	8,41	5,64	11,75	6,84	5,70	6,09	8,55	6,79	**8,26**
Cr	Igeo	-1,44	-1,78	-1,75	-1,70	-1,39	-1,93	-1,95	-2,21	-1,76	-1,66	-2,58	**-1,83**
	Ic	0,35	0,28	0,28	0,29	0,36	0,25	0,25	0,21	0,28	0,30	0,16	**0,27**
Cd	Igeo	4,88	4,63	4,51	5,45	5,79	4,58	4,72	4,56	5,84	4,30	4,89	**4,92**
	Ic	4,90	4,14	3,80	7,29	9,19	3,98	4,39	3,93	9,57	3,28	4,94	**5,40**
Pb	Igeo	0,93	1,41	0,98	0,56	0,35	0,65	1,31	0,87	0,78	0,70	0,91	**0,86**
	Ic	1,16	1,61	1,19	0,90	0,77	0,95	1,50	1,11	1,04	0,99	1,14	**1,12**

Table 5: Correlation matrix between metals and inhibition of root lengths.

	Fe	Cu	Zn	Cr	Pb	Cd	E0	E25	E50	E75	E100
Fe	1										
Cu	**0,60**	1									
Zn	**0,45**	0,13	1								
Cr	0,11	0,13	-0,18	1							
Pb	0,14	0,33	**0,54**	-0,31	1						
Cd	**0,79**	0,18	**0,65**	0,15	0,07	1					
E0	0,30	0,007	**0,66**	-0,08	0,38	0,27	1				
E25	**0,48**	0,11	**0,75**	-0,09	**0,38**	**0,43**	**0,97**	1			
E50	**0,51**	0,37	**0,80**	0,03	**0,48**	**0,47**	**0,82**	**0,87**	1		
E75	0,12	0,20	**0,59**	0,15	**0,38**	0,15	**0,55**	**0,59**	**0,77**	1	
E100	-0,11	0,22	0,29	0,21	0,34	-0,07	0,20	0,23	**0,45**	**0,84**	1

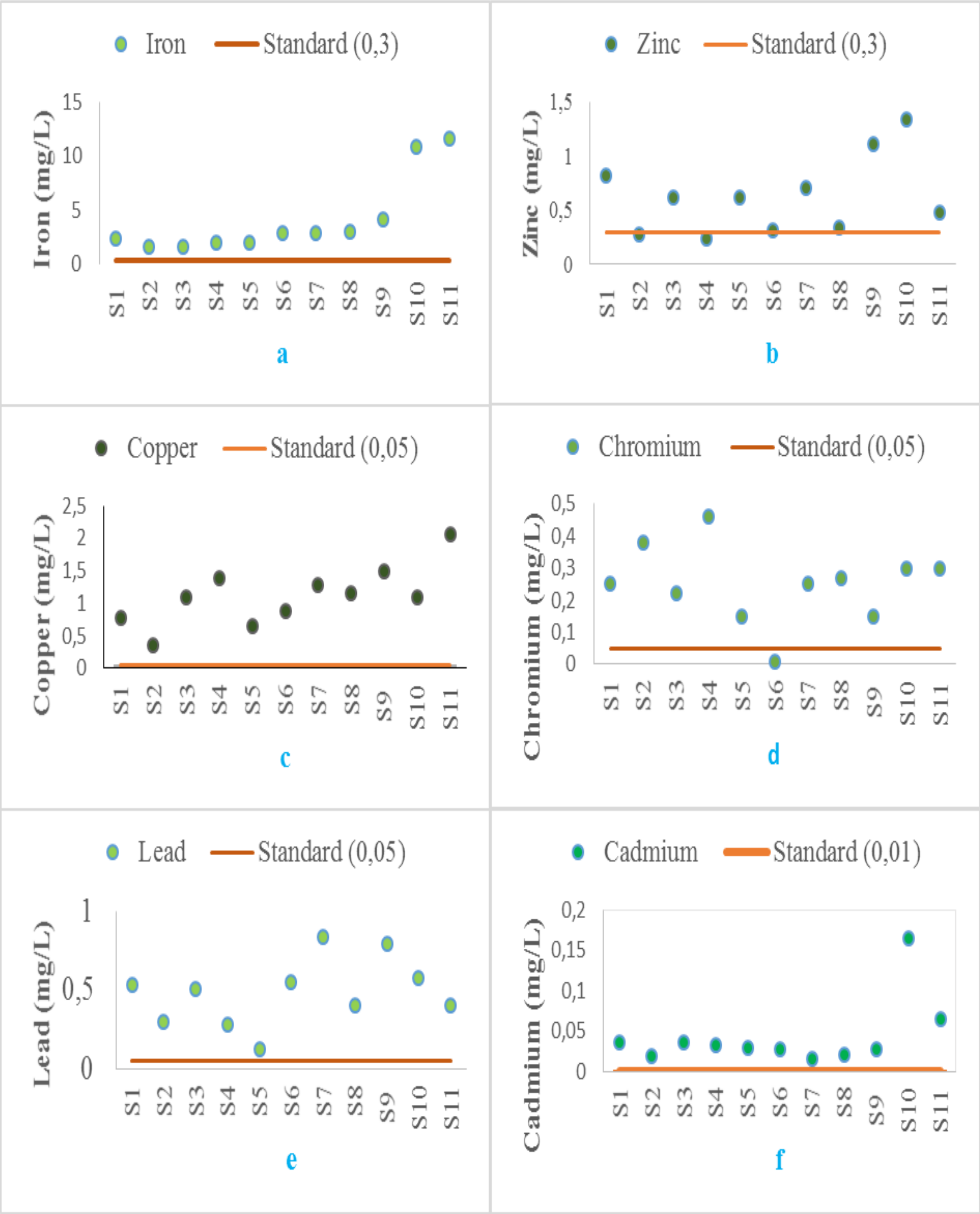

Figure 3: Spatial variation in heavy metals (Fe, Zn, Cu, Cr, Pb and Cd) levels in the Coastal Lagoon waters.

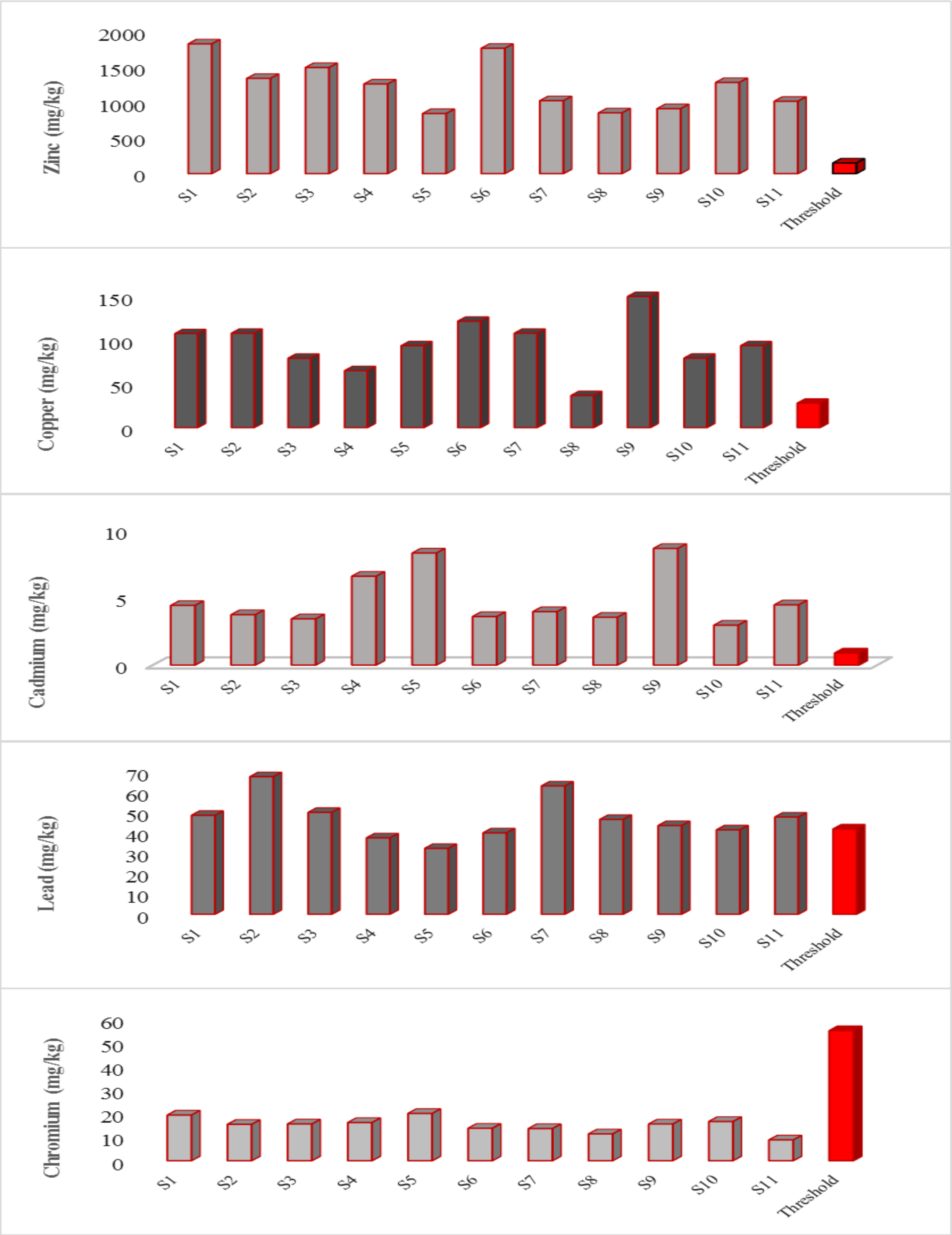

Figure 4: Spatial variation of heavy metals (Cu, Zn, Cd, Pb and Cr) in the sediments of Coastal Lagoon.

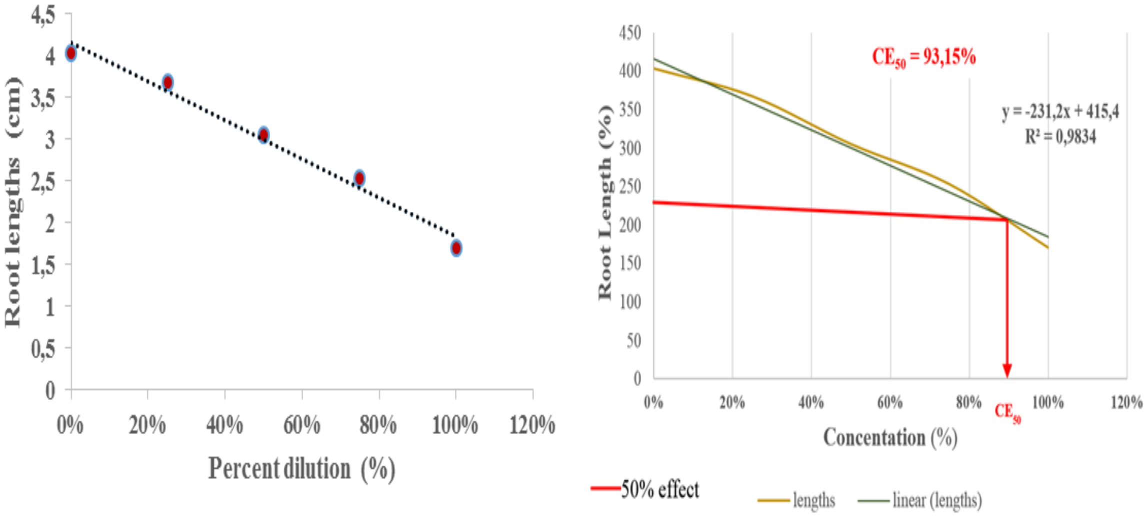

Figure 5: Inhibitory effect of lagoon water on root elongations and dose-response curve for the evaluation of the toxicity test.

DISCUSSION

The coastal lagoon of Southwest Benin is located in an area of intense human activities such as fishing in all its forms, salt farming, pig breeding, agriculture etc. These anthropic pressures interact on the ecological quality of the ecosystem. Faced with this situation, the present study was interested in the aspect of the water and sediment compartments of the said lagoon. In addition to the cytotoxicity test, the determination of heavy metals in water and sediments allowed to assess the degree of pollution of the coastal lagoon.

The measurements of the hydogen and oxidation-reduction potentials showed that the lagoon environment is reductive and characterized by slightly basic waters. The basic pH observed at all the stations favors the accumulation of heavy metals in the sediments unlike the acidic pH. Indeed, Brin (2007) stressed that at the water-sediment interface, the processes of accumulation of heavy metals are very sensitive to alkaline environment. The results of the root length inhibition test are more revealing the toxicity of the stations. Approximately 91% of the stations (10 out of 11) showed a decrease in root elongation compared to the analytical control. In contrast, station S3 shows almost identical root growth to the analytical control. The onion root length inhibition response is thought to be caused by the presence of toxic contaminants in the water. In fact, the ten (10) stations that cover the majority of the population all present high toxicities unlike the only station S3, a place of worship protected by endogenous religions. The surrounding population upstream and downstream of these ten stations generates daily massive waste directly dumped into the lagoon and its surroundings. The growth of onion roots at station S3 indicates a lack of toxicity at this station due to the fact that this station (S3) is protected by traditional rituals and has a reduced population compared to the other stations. There is a proportionality between the concentration of heavy metals in the water and the degree of inhibition of root elongation with a correlation coefficient r^2 =

0.98. Similar observations were made by Chouti et al. (2017a) in the same lagoon and Cakpo (2015) in the Porto-Novo lagoon. Given that the *Allium cepa* test has been used by many researchers mainly as a bio-indicator of environmental pollution (Leme, 2008; Bagatini et al., 2009), it is easy to conclude that the waters of the coastal lagoon are teeming with toxic pollutants that participate in the inhibition of onion root length.

The dosage of heavy metals has shown results significantly higher than the minor effects thresholds (MET) values at most stations in both water and sediment for Cd, Zn, and Cu. For these heavy metals, the highest concentrations were observed at the stations near the discharges, those downstream of the discharges and those below decks. This can be explained by the existence of toxic metallic pollutants in these discharges from anthropogenic activities that infiltrate directly or by leaching and accumulate in the sediments. Comparison of heavy metals levels in water with water quality criteria for the protection of aquatic life reveals excess of criteria for Cd, Zn and Cu for both chronic and acute effects.

In general, sediments constitute a nest of storage and metal contamination depending on the conditions of the aquatic environment. The assessment of the quality of the sediments of the coastal lagoon through the indices of contamination and geo-accumulation for Cd, Zn, and Cu highlights two classes of pollution: the first class is constituted by the sediment stations with sediments highly or even extremely charged in Cd and Zn. The second category consists of stations characterized by sediments moderately polluted by Cu. As for Pb and Cr, two classes are also observed: the third category presents stations with low Pb contents in the sediments and the last class is made up of stations not contaminated by Cr in the sediments. Coulibaly et al. (2016) obtained almost similar results in the sediments of the bay of Bietry (Ivory Coast) assessed at 2/3 of moderate or even extreme pollution according to the classification of the Igeo pollution index.

Zn is strongly present at all stations in both water and sediments. Cu comes mainly from agricultural activities (notably due to the use of copper sulphate), wastewater discharges and soil erosion. Contamination of the lagoon with Cd and Cu is believed to be related to anthropogenic activities. These results confirm those of Chouti et al. (2017a) for the same lagoon in which they discovered very high Cu and Zn grades in the water and sediments. The Cu and Zn pollution of the lagoon is becoming increasingly significant as the current grades are twice those of 2017.

These results are also similar to those of Dèdjiho (2014) and Chouti et al. (2017b) at the Ahémé lake level, which all found very high levels of Cu and Zn in the water and sediments of this lake. The sources of zinc pollution of the coastal lagoon could be explained by the inflow of water from Ahémé lake via the Aho channel. Also, the waste discharges observed at 90% of the stations could be sources of Cu and Zn contamination of the lagoon. Cu and Zn show the same trend with a remarkable increase in the downstream part of the lagoon (S1, S6). Indeed, the high pollution of Zn, Cu, and Cd within the lagoon is thought to be due to inputs from Ahémé lake separating the lagoon by 15 km, and to discharges of domestic effluents from downstream villages. According to Yehouénou (2005), the stations downstream of the discharges are much more impacted by pollution than those upstream.

The abundance of these heavy metals in the sediments is linked with the composition of the mother rock (alumino-silicates) but largely to discharges from anthropogenic activities. Cr is negligible in sediments at all stations. The lagoon is therefore not polluted by chromium. The high levels of Cr observed in the water versus the low levels in the sediment could be explained by the fact that during high water, there was a transfer of Cr loading from the sediment compartment to the water compartment of the lagoon. The Cd contents are not negligible on all sites. As for Pb, concentrations ranged from 67.7 $mg.kg^{-1}$ at station S2 to 32.4 $mg.kg^{-1}$ at station S5. Pb and Cr would be of terrigenous origin while Cu, Zn and Cd would come from anthropogenic sources. The accentuated presence of heavy metals (Zn, Cu, Cd) at the level of S1, S2, S4, S5, S6, S9, may be related to their proximity to discharges, schools, markets and technical plants. However, the sources are not identified for station S3.

The Pollution Index (PI), far exceeding 1, reflects a lagoon polluted by several heavy metals. These results are in line with those of Chouti et al. (2010), who concluded that the Porto-Novo lagoon was polluted by several heavy metals.

In this study, the ten (10) sites most exposed to discharges and agglomerations proved to be the most polluted, unlike the only site isolated from discharges and protected by endogenous cults. The waters and sediments of the coastal lagoon of Southwest Benin are thus 90% influenced by anthropic activities and 10% by natural phenomena. The trends indicate a metal pollution strongly anthropized within the lagoon.

Conclusion

Anthropogenic activities generate solid household waste and wastewater which, discharges of into aquatic environments, without any prior treatment, can have serious and irreversible consequences on the aquatic ecosystem, which is the receiving environment. The objective of this study was to characterize the state of the coastal lagoon and its degree of iron, copper, zinc, chromium, cadmium and lead toxicity during high water periods in order to estimate the eco-toxicological risks to which fish species and population are exposed. The results showed that the waters and sediments of the coastal lagoon are characterized by the presence of Cu, Zn, Cr, Cd and Pb at all the stations but more particularly Cu, Cd and Zn. Levels of these heavy metals in both water and sediments are non-standard at most stations. This constitutes a high risk for the aquatic environment. This study highlights a problem of toxic exposure related to the contamination of the lagoon with heavy metals, especially in Togbin, Djègbadji and Avlo. Waste management must be reviewed at the level of this water body.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

OBMLB has initiated and developed the research. WKC and DM coordinated and contributed to the writing process. RAC participated in the analysis protocol. All authors read and approved the final manuscript.

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