

The Contamination Levels of Water and Sediment from Lake Togo by the Persistent Organic Pollutants (Pops)

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Abstract: This study was carried out to evaluate the contamination severity of Lake Togo by organochlorinated pesticides historically used in agriculture and in health programs against disease vectors in public health. A total of 48 samples of sediments and 48 samples of water were seasonally collected. For both sediment and water 3 samples per site were collected at 8 sites in the 2014 rainy season and in the 2015 dry season. Water samples were processed using a liquid-liquid method solvent extraction while Soxhlet extraction was used for sediment samples. The sediment and water extractions were cleaned-up and qualitative-quantitative analysis performed on gas chromatograph equipped with electron capture detector (GC-ECD). Pesticides residue levels in water ranged from < 0.001 to $0.093 \pm 0.20 \mu\text{g l}^{-1}$ (lindane) in rainy season and from < 0.001 to $0.352 \pm 0.07 \mu\text{g l}^{-1}$ (dieldrin) in dry season. They were lower than that found in sediment which ranged from < 0.001 to $0.98 \pm 0.18 \mu\text{g kg}^{-1}$ dry weight (pp'-DDE) in rainy season and from < 0.001 to $2.19 \pm 0.31 \mu\text{g kg}^{-1}$ dry weight (heptachlor epoxide) in dry season. The concentrations of the organochlorinated residues in water and sediment were higher during the dry season. Except pp'-DDE, pp'-DDD, heptachlor and heptachlor epoxide, the others pesticide residues concentrations detected in water samples in dry season were above the maximum acceptable concentration of $0.1 \mu\text{g l}^{-1}$ for individual pesticides set by the European Union (EU) for the protection of human health. Pesticide contamination level of Lake Togo is therefore, likely to be harmful to human health in dry season.

Keywords: Lake Togo, Water, Sediment, Contamination, Organochlorine Pesticides

1. Introduction

African countries were considered to be safe from water bodies' pollution in the past. Thorslund [1] concluded that the pollution of aquatic environments in African countries was not a concern. Nevertheless, such a statement may be subject to debate in our days because more recent studies [2-4] demonstrate that the high anthropogenic activities have resulted in a remarkable amount of persistent organic pollutants (POPs) such as organochlorine pesticides and diversity of discharges reaching aquatic environment. Studies [5, 6] established the relationship between human exposure to organochlorine pesticides and several pathologies such as human infertility, defect births, brain tumors as well as breast

and prostate cancer etc. Organochlorine pesticides are an important group of persistent organic pollutants (POPs) which are toxic, persistent, bio-accumulative and have the ability of a long-run transport potential [7]. In the recent years, there is a growing interest to POPs due to their potential toxicity and adverse impacts on human health [7]. The Stockholm Convention on POPs in 2001 is an outcome of this growing concern about the persistent organic pollutants including organochlorine pesticides. The organochlorine pesticides targeted by the Stockholm Convention were used in agriculture and in public health vector control. By 1970s, these pesticides were either banned or were subject to restricted uses in many countries. Though banned, some of these chemicals are still being used in some

of the developing countries for agriculture and public health based purposes. For examples in Africa: Mozambique, Zambia and Zimbabwe reported their recent re-introduction of DDT use for malaria control [8] while endosulfan is still illegally used on vegetables in the littoral area of Togo [9].

In Togo, the use of chemical pesticides dates back to the colonial period to protect coffee, cocoa and cotton crops and in the fight against disease vectors as malaria etc. The most commonly used pesticides were the organochlorinated compounds [10, 11]. These compounds generally referred to dichlorodiphenyltrichloroethane (DDT) group, cyclodienes compounds (aldrin, dieldrin, endrin, endosulfan and heptachlor), isomers of hexachlorocyclohexanes (α -, β -, γ -, δ -HCH) and others [10, 11]. In order to protect the population against the harmful effects of pesticides, Togolese government took several decrees to regulate the trade of plant protection products and has signed and / or ratified international legal agreements including the Stockholm Convention on POPs signed 23 May 2001 and ratified 22 July 2004, the international code of conduct on the management of pesticides, adopted in June 2013 by Resolution 3/2013 amending the International Code of Conduct on the Distribution and Pesticide Use on 1 November 2002.

This work is part of the human-based exposure risk assessment because of the contamination of his environment. Lake Togo is one of the important water bodies that surrounding local communities use mainly for fishing, swimming and boat transport. The communities also use the water from the lake for drinking and several other household uses. Recent studies in neighboring countries, Ghana [2] and Benin [12], have revealed the presence of organochlorine pollutants in aquatic environment. Thus, the Lake Togo likely has received some amount of pollution as a result of anthropogenic activities. The sediment found on river and lake beds is one of the important sink and reservoir for persistent pollutants discharged into the environment [13]. The water body quality depends on the quality of sediment. Though regarded as a sink, the sediment may release back to overlying waters the pollutants bound on it, as a result of remobilization due to various processes [14]. Thus, historically contaminated sediments are reservoirs from which old organochlorine pesticides can disseminate in the environment [15]. Little or no attention, however, has been given to the potential contamination of sediment in Lake Togo.

2. Material and Methods

2.1. The Study Area

Togo is a long, narrow country in West Africa between Ghana and Benin. Lake Togo, the study site, is the largest natural body in west of Togolese lagoon system and situated at the latitude and longitude coordinates of 6°24.30 N and 1°42.33 E (Figure 1). It extends in the east by the lagoon of Togoville, the lagoon of Aneho and the lagoon of Vogan

which constitutes a small water reservoir in north-east (Figure 1). The Lake Togo covers an area of about 46 km² while the entire lagoon system have a total area of 68 km² and powered by three main Rivers Zio, Haho and Boko draining a watershed of 7200 km² [16]. The Lake Togo is one of the main income sources for surrounding communities. They heavily depend on fishing for their income and food. Besides fishing, the Lake provides the basis for other social and economic opportunities such as transportation and tourism.

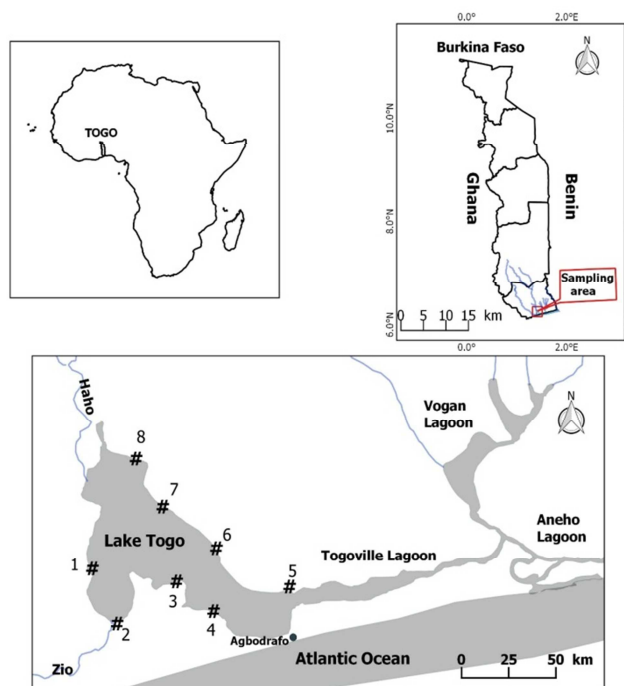


Figure 1. Map of Lake Togo in Republic of Togo and African continent with water and sediment sampling sites indicated by number: 1 = Abobo site, 2 = Amedehoeve site, 3 = Agomekpota site, 4 = Kpessi site, 5 = Togoville site, 6 = Ekpou site, 7 = Adjido site, 8 = Seva-Tonou site.

2.2. Water and Sediment Sampling

The sampling of sediment and water was conducted seasonally during rainy season in June 2014 and dry season in January 2015. The sampling was carried out according to the standard protocol as described in APHA [17]. Water and sediment samples were collected from eight sites around the Lake including Abobo site (06°23.768' N, 001°38.736' E), Amedehoeve site (06°21.677' N, 001°39.851' E), Agomekpota site (06°23.622' N, 001°42.824' E), Kpessi site (06°22.223' N, 001°44.177' E), Togoville site (06°23.042' N, 001°47.919' E), Ekpou site (06°24.749' N, 001°44.589' E), Adjido site (06°27.274' N, 001°41.568' E) and Seva-Tonou site (06°29.219' N, 001°40.650' E) (figure 1). Samples were taken from surface parts of the water and sediment. At each sampling site five sub-samples of surface sediments (top 10 cm layer) were randomly taken using stainless steel hand trowel [18, 19] and pulled together to form a representative composite sample. Each sampling was carried out in three replicates. Sediment samples were

collected in pre-cleaned glass bottles wrapped with aluminum foil and protected from direct sunlight. Surface water samples were taken at the same points as in the case of sediment. At each sampling point five sub-samples (500 ml) of surface water were randomly taken and pulled together to form a representative composite sample. The water samples were also all run in triplicate ($n = 3$) at each sampling site and stored in a pre-cleaned glass bottle protected from direct sunlight. A total of 48 samples of sediments and 48 samples of water were collected randomly, either 3 samples per site in 8 sites = 24 samples each of sediments and water in rainy season (June 2014) and repeated in dry season (January 2015). All samples collected (water and sediments) were immediately stored in an ice-chest at 4°C and transported to the laboratory for analysis. In the laboratory, the water samples were kept in fridge at a temperature of about 4°C and the sediment samples were dried at room temperature. The sediments were then milled with pestle and mortar and then sieved through a 2 mm sieve to remove stones and other debris. The sieved samples were then kept at room temperature in a clean cupboard.

2.3. Characterization of Sediments

Sediment particle size distribution was determined using hydrometer method [20]. The soil textural class of USDA (United States Department of Agriculture) was used for the classification of sediment texture [21]. Organic carbon content was measured using oxidation method as modified by Nelson and Sommers [22] while organic matter was obtained by multiplying the organic carbon content by 1.724. The pH in H₂O was determined by conventional standard procedures using the glass electrode method [23].

2.4. Sediment Extraction

The water layer over the sediment was decanted and discarded. The sediment was mixed to obtain a homogenous sample and then transferred to a pan to air-dry at ambient temperature. Ten grams (dry weight) of the sample was weighed into an extraction thimble (pre-cleaned) and extracted with 180 ml of appropriate solvent (hexane: acetone (3:1 v/v)) for 8 h in a Soxhlet apparatus cycling 4 - 5 times per hour. A solvent (isooctane) was added to the eluate as a keeper and the cooled extract was then concentrated on the rotary evaporator at 45°C to near dryness and made ready for clean-up.

2.5. Water Extraction

The water samples were filtered immediately through a Whatman GF/F filter (0.7 µm porosity) previously heated at 450°C and covered with aluminium foil to avoid the degradation by sun light. Subsequently, filtered samples were stored at 4°C until analysis. Pesticides were extracted from the water according to the method described by Essumang et al. [24] with slight modification. An aliquot of 500 ml of the aqueous sample was measured and transferred into a 1000 ml

separatory funnel and extracted with 3x50 ml hexane. The separatory funnel was clapped for 30 min to allow phase separation. The combined organic phases were collected into a 500 ml beaker with the aqueous phase discarded. The combined organic layer was then dried of any aqueous substance with 20 g of anhydrous sodium sulphate and allowed to settle. The organic content was then decanted into a 300 ml round bottom flask and the content evaporated to dryness using the rotary evaporator at 45°C to near dryness and made ready for clean-up.

2.6. Clean-up Process

Glass chromatographic columns were packed with 4 g of deactivated SiO₂, 0.5 g of Na₂SO₄ and 6 g of alumina, 1 g of sodium sulphate (Na₂SO₄), 1 g of activated charcoal respectively for water and sediment clean up. The columns were rinsed by 10 ml of hexane. Hexane (40 ml) was added to the concentrate (water and sediment) in a ratio of 2:1:1 to rinse the round bottomed flask thoroughly and the extract was carefully transferred onto the clean-up column by using a glass Pasteur pipette. The eluate was allowed to run into a receiving flask and then concentrated to dryness. The concentrate was picked in 2 ml ethyl acetate into a well-labelled G.C. sample vial for gas chromatography analysis.

2.7. Qualitative and Quantitative Analysis

Each sample was analysed in triplicate through the described residue analytical procedure [25]. Triplicate injections of one micro litre from each of the final residue solutions was injected into the Shimadzu GC 2010, gas chromatograph equipped with an Electron Capture detector. The chromatographic separation was done on an SGE BPX-5 of 60 m capillary column with 0.25 mm internal diameter and 0.25 µm film thickness and equipped with 1m retention gap (0.53 mm, deactivated). The oven temperature programme was as follows: Initial temperature was set at 90°C for 3 min and ramped at 30°C /min to 200°C for 15 min and then to 265°C at a rate of 5°C /min for 5 min then to 275°C at the rate of 3°C /min and allowed to stay for 15 min giving a total run time of 58 min. The injector setting is a pulsed splitless mode with a temperature of 250°C at a pressure of 1.441 bar. Pulsed pressure was 4.5 bar, pulsed time 1.5 min and purge flow of 55.4 ml/min with a purge time of 1.4 min. The detector temperature was 300°C in "constant makeup flow" mode (30 ml/min of Nitrogen gas). The qualitative identification of the organochlorine pesticides present in the real samples was performed by comparing the Relative Retention Times (RRT) with respect to the internal standard, for each peak in the real sample chromatogram to those (RRT) in the standard mixture chromatogram. The quantitative determination was performed by using the Relative Peak Areas (RPA) and the Relative Concentrations (RC). The detection limit was 0.001 µg l⁻¹ or 0.001 µg kg⁻¹. Average of triplicate injection values was taken and means values were arrived within the three replicates.

2.8. Control Quality

The quality of this study was assured through the analysis of standard solution (isodrin) and blank samples included in each batch of samples. This was performed by spiking with known concentrations of the internal standard to the water and sediment. The analysis of the spiked samples was performed according to the above mentioned procedure. The recovery of internal standards ranged 87 to 104% and 86 to 103% sediment and water samples, respectively.

2.9. Statistical Analysis

Laboratory analytical results were subjected to analysis of variance (ANOVA) using SAS software, version 9.2, 2nd edition of 2010. Separation of the means was performed using Duncan significance test ($p < 0.05$).

3. Results and Discussion

3.1. Sediment Characteristics

The sediments are presented as the mixture of detritus, inorganic and organic particles resulting from soil erosion found as sludge and vases on lake bed. The particle size distributions of sediments from different sites of Lake Togo showed a large variability (Table 1). Most of the sediments were sandy, except for the samples collected from Amedehoeve, Agomekpota and Kpessi that had very high silt and clay contents and therefore were silty clay loam in nature. It may be explained by the fact that these sampling points are situated at a lower topographic position relative to the other points (Figure 1). The organic matter contents were also much higher at these three sites than at the others. Our findings are in agreement with the findings of Yehouenou *et al.* [12] who also investigated sediment characteristics in Lake Nokoué and Cotonou Lagoon in Benin.

Table 1. Sediments characteristics.

Sampling sites	pH - water	Organic matter (%)	Clay (%)	Silt (%)	Sand (%)
Abobo	7.6	3.24	2.6	4.1	93.0
Amedehoeve	7.9	9.3	30.9	54.3	14.4
Agomekpota	8.1	10.6	33.3	54.0	12.2
Kpessi	8.2	9.80	31.5	54.5	13.6
Togoville	7.7	2.53	3.2	4.4	92.1
Ekpoui	7.8	2.10	2.8	4.2	92.5
Adjido	7.7	2.9	3.2	3.1	93.2
Seva-Tonou	7.6	1.58	1.6	3.9	94.1

3.2. Pesticide Residue Concentrations in Water and Sediment from Lake Togo

The means concentrations based on triplicate determination of the organochlorine pesticides residues in water and sediment samples are presented in Tables 2, 3, 4 and 5. From the compounds examined, residues of pp'-DDE, pp'-DDD, lindane (γ -HCH), α -HCH, aldrin, dieldrin, endrin, heptachlor, heptachlor epoxide, α -endosulfan, β -endosulfan, endosulfan sulphate were detected and quantified in samples analyzed while the compounds pp'-DDT, op'-DDT, hexachlorobenzene (HCB), β -HCH, δ -HCH, Mirex and trans-nonachlor could not be observed because their concentrations were below the limit of detection ($LOD < 0.001 \mu\text{g l}^{-1}$ and $< 0.001 \mu\text{g kg}^{-1}$). The presence of organochlorine pesticides in Lake Togo could be attributed to historical use of these chemicals by farmers in watershed covering 7 200 km² drained by Zio, Haho and Boko Rivers which powered entire Togolese lagoon system. Their presence in Lake Togo could be all so attributed to their persistence because the usage of most among them was banned in Togo more than 30 years ago [11]. They are likely to originate from atmospheric deposition and runoff which washes and releases pesticides bound to soil particles and other matrixes from treated areas directly to water bodies [26].

Analysis of the sediment samples revealed the presence of twelve persistent pesticide residues (Tables 3 and 5) while eight were measured in water (Tables 2 and 4). Neither pp'-

DDT nor its metabolites (pp'-DDE or pp'-DDD); neither heptachlor nor heptachlor epoxide were detected in water samples. However, the residues of pp'-DDE, pp'-DDD, heptachlor and heptachlor epoxide were quantified in the sediment samples at average concentrations of $<0.001 - 0.98 \pm 0.18 \mu\text{g kg}^{-1}$, $<0.001 - 0.69 \pm 0.13 \mu\text{g kg}^{-1}$, $<0.001 - 0.74 \pm 0.11 \mu\text{g kg}^{-1}$, and $<0.001 - 0.69 \pm 0.5 \mu\text{g kg}^{-1}$ dry weight respectively in rainy season against $<0.001 - 1.49 \pm 0.15 \mu\text{g kg}^{-1}$, $<0.001 - 1.07 \pm 0.4 \mu\text{g kg}^{-1}$, $<0.001 - 1.22 \pm 0.07 \mu\text{g kg}^{-1}$, and $<0.001 - 2.19 \pm 0.31 \mu\text{g kg}^{-1}$ dry weight respectively in dry season. It suggests that these compounds accumulate in sediment when they are discharged into water bodies. It may be also attributed to the fact that they are not very soluble in water and therefore more likely to adsorb in sediments [27]. Lindane was detected with the lower concentration ($<0.001 - 0.326 \pm 0.4 \mu\text{g l}^{-1}$) in water and the highest concentration in sediment $<0.001 - 1.37 \pm 0.17 \mu\text{g kg}^{-1}$ dry weight in dry season while its concentrations were $<0.001 - 0.093 \pm 0.20 \mu\text{g l}^{-1}$ in water and $< 0.001 - 0.89 \pm 0.08 \mu\text{g kg}^{-1}$ dry weight in sediment in rainy season. These results suggest that lindane is more prevalent and persistent in the sediments than in water. Its isomer α -HCH was detected in sediment at $<0.001 - 0.96 \pm 0.11 \mu\text{g kg}^{-1}$ dry weight against $<0.001 - 0.295 \pm 0.1 \mu\text{g l}^{-1}$ in water in dry season against $<0.001 - 0.68 \pm 0.30 \mu\text{g kg}^{-1}$ dry weight and $<0.001 - 0.052 \pm 0.02 \mu\text{g l}^{-1}$ respectively in rainy season. The highest concentration of α -endosulfan $1.75 \pm 0.61 \mu\text{g kg}^{-1}$ dry weight was detected in the sediment sample in dry season. Mean levels of α -endosulfan in the

sediments is about 11 times the levels measured in water either $0.159 \pm 0.11 \mu\text{g l}^{-1}$. The β -endosulfan and endosulfan sulphate were measured in sediment at $<0.001 - 0.86 \pm 0.40 \mu\text{g kg}^{-1}$ and $<0.001 - 1.09 \pm 0.06 \mu\text{g kg}^{-1}$ dry weight against $<0.001 - 0.125 \pm 0.3 \mu\text{g l}^{-1}$ and $<0.001 - 0.167 \pm 0.19 \mu\text{g l}^{-1}$ in water respectively in dry season while they were found at concentrations of $<0.001 - 0.56 \pm 0.13 \mu\text{g kg}^{-1}$ and $<0.001 - 0.69 \pm 0.41 \mu\text{g kg}^{-1}$ dry weight in sediment against $<0.001 - 0.045 \pm 0.01 \mu\text{g l}^{-1}$ and $<0.001 - 0.051 \pm 0.02 \mu\text{g l}^{-1}$ in water respectively in rainy season. In dry season, the residues of aldrin, dieldrin and endrin were found in sediment at

concentrations ranged from <0.001 to $1.58 \pm 0.26 \mu\text{g kg}^{-1}$ dry weight, <0.001 to $2.05 \pm 0.31 \mu\text{g kg}^{-1}$ dry weight and from <0.001 to $1.41 \pm 0.55 \mu\text{g kg}^{-1}$ dry weight respectively while they were measured in water at $<0.001 - 0.320 \pm 0.3 \mu\text{g l}^{-1}$, $<0.001 - 0.352 \pm 0.07 \mu\text{g l}^{-1}$ and $<0.001 - 0.329 \pm 0.2 \mu\text{g l}^{-1}$ respectively. However, they were detected in lower levels in rainy season in sediment at concentrations of $<0.001 - 0.68 \pm 0.25 \mu\text{g kg}^{-1}$ dry weight, $<0.001 - 0.86 \pm 0.12 \mu\text{g kg}^{-1}$ dry weight, $<0.001 - 0.69 \pm 0.03 \mu\text{g kg}^{-1}$ dry weight and $<0.001 - 0.054 \pm 0.03 \mu\text{g l}^{-1}$, $<0.001 - 0.059 \pm 0.02 \mu\text{g l}^{-1}$, $<0.001 - 0.043 \pm 0.01 \mu\text{g l}^{-1}$ in water respectively.

Table 2. Levels of organochlorine pesticide residues in water ($\mu\text{g l}^{-1}$) at different points from Lake Togo in rainy season (June 2014).

Sampling sites	pp'-DDE	pp'-DDD	γ -HCH (lindane)	α -HCH	aldrin	dieldrin
Abobo	< 0.001	< 0.001	0.025 ± 0.02	< 0.001	< 0.001	0.033 ± 0.01
Amedehoeve	< 0.001	< 0.001	0.055 ± 0.05	0.025 ± 0.01	0.036 ± 0.10	< 0.001
Agomekpota	< 0.001	< 0.001	0.093 ± 0.20	0.052 ± 0.02	0.054 ± 0.03	0.039 ± 0.02
Kpessi	< 0.001	< 0.001	< 0.001	< 0.001	0.045 ± 0.01	0.059 ± 0.02
Togoville	< 0.001	< 0.001	0.039 ± 0.01	0.026 ± 0.02	< 0.001	0.019 ± 0.0
Ekpoui	< 0.001	< 0.001	< 0.001	0.028 ± 0.01	0.017 ± 0.0	< 0.001
Adjido	< 0.001	< 0.001	0.021 ± 0.01	< 0.001	< 0.001	0.031 ± 0.01
Seva-Tonou	< 0.001	< 0.001	0.022 ± 0.01	0.015 ± 0.0	0.032 ± 0.01	0.023 ± 0.02

Table 2. Continue.

Sampling sites	endrin	heptachlor	heptachlor epoxide	α -endosulfan	β -endosulfan	Endosulfan sulphate
Abobo	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.023 ± 0.01
Amedehoeve	0.034 ± 0.02	< 0.001	< 0.001	0.025 ± 0.01	0.045 ± 0.01	0.033 ± 0.01
Agomekpota	0.043 ± 0.01	< 0.001	< 0.001	< 0.001	0.041 ± 0.02	0.024 ± 0.02
Kpessi	< 0.001	< 0.001	< 0.001	0.035 ± 0.02	0.044 ± 0.04	0.051 ± 0.02
Togoville	0.027 ± 0.01	< 0.001	< 0.001	0.026 ± 0.02	0.032 ± 0.01	0.027 ± 0.01
Ekpoui	0.016 ± 0.01	< 0.001	< 0.001	< 0.001	< 0.001	0.021 ± 0.02
Adjido	0.025 ± 0.01	< 0.001	< 0.001	0.032 ± 0.01	0.013 ± 0.0	0.029 ± 0.02
Seva-Tonou	< 0.001	< 0.001	< 0.001	0.025 ± 0.01	0.018 ± 0.0	0.012 ± 0.0

Table 3. Levels of organochlorine pesticide residues in sediment ($\mu\text{g kg}^{-1}$) at different points from Lake Togo in rainy season (June 2014).

Sampling sites	pp'-DDE	pp'-DDD	γ -HCH (lindane)	α -HCH	aldrin	dieldrin
Abobo	<0.001	<0.001	0.58 ± 0.01	0.54 ± 0.19	<0.001	< 0.001
Amedehoeve	0.64 ± 0.08	0.59 ± 0.43	0.75 ± 0.10	0.68 ± 0.30	0.63 ± 0.8	0.86 ± 0.12
Agomekpota	0.90 ± 0.15	<0.001	0.89 ± 0.08	0.61 ± 0.04	0.68 ± 0.25	0.59 ± 0.07
Kpessi	0.98 ± 0.18	0.69 ± 0.13	0.79 ± 0.13	0.57 ± 0.02	0.66 ± 0.3	0.54 ± 0.06
Togoville	<0.001	0.54 ± 0.01	<0.001	<0.001	0.56 ± 0.3	<0.001
Ekpoui	0.95 ± 0.26	<0.001	<0.001	<0.001	<0.001	0.54 ± 0.05
Adjido	0.88 ± 0.06	0.65 ± 0.05	0.61 ± 0.03	0.55 ± 0.02	<0.001	<0.001
Seva-Tonou	<0.001	<0.001	0.64 ± 0.01	0.57 ± 0.02	<0.001	< 0.001

Table 3. Continue.

Sampling sites	endrin	heptachlor	heptachlor epoxide	α -endosulfan	β -endosulfan	Endosulfan sulphate
Abobo	<0.001	<0.001	0.53 ± 0.21	<0.001	<0.001	< 0.001
Amedehoeve	0.64 ± 0.30	0.56 ± 0.31	0.62 ± 0.08	0.62 ± 0.19	0.55 ± 0.3	< 0.001
Agomekpota	0.55 ± 0.41	0.66 ± 0.12	0.69 ± 0.5	<0.001	0.56 ± 0.13	0.69 ± 0.41
Kpessi	0.69 ± 0.03	<0.001	0.53 ± 0.61	0.88 ± 0.2	<0.001	0.63 ± 0.31
Togoville	<0.001	0.58 ± 0.05	<0.001	0.51 ± 0.28	0.54 ± 0.18	0.59 ± 0.22
Ekpoui	0.69 ± 0.31	<0.001	0.59 ± 0.25	0.56 ± 0.2	< 0.001	0.56 ± 0.32
Adjido	<0.001	<0.001	<0.001	0.81 ± 0.04	0.51 ± 0.1	< 0.001
Seva-Tonou	0.56 ± 0.11	0.74 ± 0.11	<0.001	<0.001	<0.001	0.58 ± 0.29

Table 4. Levels of organochlorine pesticide residues in water ($\mu\text{g l}^{-1}$) at different points from Lake Togo in dry season (January 2015).

Sampling sites	pp'-DDE	pp'-DDD	γ -HCH (lindane)	α -HCH	aldrin	dieldrin
Abobo	< 0.001	< 0.001	0.21 \pm 0.11	< 0.001	< 0.001	0.290 \pm 0.2
Amedehoeve	< 0.001	< 0.001	< 0.001	0.229 \pm 0.25	0.316 \pm 0.12	0.291 \pm 0.4
Agomekpota	< 0.001	< 0.001	0.326 \pm 0.4	0.295 \pm 0.1	0.313 \pm 0.3	0.352 \pm 0.07
Kpessi	< 0.001	< 0.001	0.275 \pm 0.10	0.290 \pm 0.27	0.320 \pm 0.3	0.240 \pm 0.1
Togoville	< 0.001	< 0.001	0.234 \pm 0.43	0.218 \pm 0.20	< 0.001	< 0.001
Ekpoui	< 0.001	< 0.001	< 0.001	0.245 \pm 0.03	< 0.001	0.273 \pm 0.31
Adjido	< 0.001	< 0.001	0.288 \pm 0.26	< 0.001	< 0.001	0.235 \pm 0.31
Seva-Tonou	< 0.001	< 0.001	0.219 \pm 0.27	0.257 \pm 0.4	< 0.001	0.313 \pm 0.2

Table 4. Continue.

Sampling sites	endrin	heptachlor	heptachlor epoxide	α -endosulfan	β -endosulfan	Endosulfan sulphate
Abobo	0.262 \pm 0.11	< 0.001	< 0.001	0.127 \pm 0.3	< 0.001	0.122 \pm 0.2
Amedehoeve	0.329 \pm 0.2	< 0.001	< 0.001	0.149 \pm 0.15	0.125 \pm 0.3	0.139 \pm 0.31
Agomekpota	0.215 \pm 0.3	< 0.001	< 0.001	< 0.001	< 0.001	0.167 \pm 0.19
Kpessi	0.329 \pm 0.2	< 0.001	< 0.001	0.159 \pm 0.11	0.114 \pm 0.11	0.132 \pm 0.21
Togoville	0.314 \pm 0.4	< 0.001	< 0.001	0.154 \pm 0.06	< 0.001	0.129 \pm 0.2
Ekpoui	< 0.001	< 0.001	< 0.001	0.119 \pm 0.30	0.111 \pm 0.04	0.109 \pm 0.3
Adjido	< 0.001	< 0.001	< 0.001	< 0.001	0.121 \pm 0.04	0.117 \pm 0.2
Seva-Tonou	0.222 \pm 0.02	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Table 5. Levels of organochlorine pesticide residues in sediment ($\mu\text{g kg}^{-1}$) at different points from Lake Togo in dry season (January 2015).

Sampling sites	pp'-DDE	pp'-DDD	γ -HCH (lindane)	α -HCH	aldrin	dieldrin
Abobo	1.44 \pm 0.01	< 0.001	< 0.001	< 0.001	< 0.001	1.63 \pm 0.8
Amedehoeve	0.59 \pm 0.08	0.82 \pm 0.31	0.68 \pm 0.43	0.51 \pm 0.03	1.58 \pm 0.26	2.05 \pm 0.31
Agomekpota	1.49 \pm 0.15	< 0.001	1.37 \pm 0.17	0.96 \pm 0.11	1.44 \pm 0.19	0.94 \pm 0.25
Kpessi	<0.001	0.91 \pm 0.03	1.09 \pm 0.01	<0.001	1.05 \pm 0.18	1.06 \pm 0.3
Togoville	0.58 \pm 0.02	< 0.001	< 0.001	0.58 \pm 0.01	1.03 \pm 0.21	< 0.001
Ekpoui	0.53 \pm 0.26	1.07 \pm 0.4	<0.001	<0.001	< 0.001	1.27 \pm 0.4
Adjido	0.89 \pm 0.06	0.54 \pm 0.21	0.83 \pm 0.05	0.90 \pm 0.08	< 0.001	< 0.001
Seva-Tonou	<0.001	0.51 \pm 0.05	0.83 \pm 0.04	0.52 \pm 0.01	<0.001	< 0.001

Table 5. Continue.

Sampling sites	endrin	heptachlor	heptachlor epoxide	α -endosulfan	β -endosulfan	Endosulfan sulphate
Abobo	< 0.001	< 0.001	< 0.001	0.98 \pm 0.39	< 0.001	< 0.001
Amedehoeve	1.17 \pm 0.24	1.09 \pm 0.03	1.14 \pm 0.38	1.03 \pm 0.31	0.69 \pm 0.08	1.02 \pm 0.12
Agomekpota	1.40 \pm 0.26	1.22 \pm 0.07	2.09 \pm 0.41	1.19 \pm 0.12	0.86 \pm 0.40	1.09 \pm 0.06
Kpessi	1.41 \pm 0.55	< 0.001	2.19 \pm 0.31	1.75 \pm 0.61	0.53 \pm 0.61	0.89 \pm 0.18
Togoville	1.07 \pm 0.52	1.06 \pm 0.12	< 0.001	< 0.001	< 0.001	0.96 \pm 0.13
Ekpoui	< 0.001	< 0.001	< 0.001	< 0.001	0.59 \pm 0.25	< 0.001
Adjido	< 0.001	< 0.001	2.11 \pm 0.21	1.25 \pm 0.32	< 0.001	< 0.001
Seva-Tonou	1.02 \pm 0.3	1.07 \pm 0.44	< 0.001	< 0.001	<0.001	< 0.001

In general, the concentration of organochlorine pesticides residues in water was lower than that of sediment samples. This may be attributed to the fact that they have an affinity for particulate matter and one of their main sinks is thought to be river and lake sediments [28]. When pesticide molecules can dissolve in water, a large proportion binds to suspended particles and settles at the bottom of the water body with production of contaminated sediments [29]. Some pesticides, particularly organochlorine with hydrophobic nature and low water solubility can be retained on the organic phase of sediments through sorption, and thus found in higher concentrations than those detected in the overlying waters [30].

To evaluate the relative degree of water contamination in Lake Togo, present study data were compared to available maximum residue set by limit of international norms. The pesticide residues concentrations detected in water samples

in dry season were generally above the maximum acceptable concentration of 0.1 $\mu\text{g l}^{-1}$ for individual pesticides set by the European Union (EU) for the protection of human health [31]. The concentrations of α -endosulfan, β -endosulfan and endosulfan sulphate in water of Lake Togo were all below the US EPA standards for safe drinking water of 0.2 $\mu\text{g l}^{-1}$ [32] during both rainy and dry seasons. The lindane (γ -HCH) and its isomer α -HCH concentrations in water obtained in this study are well above the US EPA and WHO guidelines. The US EPA recommends a maximum contaminant level (MCL) of 0.2 $\mu\text{g l}^{-1}$ for individual HCH isomers in drinking water [32], whereas WHO recommended maximum residual level (MRL) is 0.3 $\mu\text{g l}^{-1}$ [33]. Levels of organochlorine pesticide residues in water collected from Lake Togo were comparable or lower than those recorded in water from Lake Bosomtwe in Ghana (<0.01 - 6.35 $\mu\text{g l}^{-1}$) [2], water from the river Ogbese in Nigeria (from below detection limit to 13.6 $\mu\text{g l}^{-1}$)

[34] and from four rivers in Tanzania (from below detection limit to $0.12 \mu\text{g l}^{-1}$) [27].

Comparison of the results from our study to those recorded in previous studies reveals that the residue levels found in sediment from Lake Togo were generally comparable or lower than those from others Lakes or Rivers in Africa, Iraq, Malaysia and India. The residue levels of pp'-DDE, pp'-DDD, lindane (γ -HCH) and its isomer α -HCH, aldrin, dieldrin, endrin, heptachlor, heptachlor epoxide, α -endosulfan, β -endosulfan and endosulfan sulphate found in sediment from Lake Togo were comparable or lower than that of Lake Bosomtwe in Ghana (<0.01 to $15.23 \mu\text{g kg}^{-1}$) [2], of the river Ogbese in Nigeria ($0.52 - 450 \mu\text{g kg}^{-1}$) [34], of the Uganda side of Lake Victoria (non-detectable (ND) to $5.62 \mu\text{g kg}^{-1}$) [4], of four rivers running through sugarcane plantations, Kilimanjaro in Tanzania (trace to $132 \mu\text{g kg}^{-1}$) [27], of Euphrates river in Iraq ($29.389 - 211.104 \mu\text{g g}^{-1}$) [35], and of sediment from Cameron highlands in Malaysia ($0.41 - 82.16 \mu\text{g kg}^{-1}$) and from the river Yamuna Delhi in India ($157.71 - 307.66 \mu\text{g kg}^{-1}$ in Pre-monsoon, $195.86 - 577.74 \mu\text{g kg}^{-1}$ in Monsoon and $306.9 - 844.45 \mu\text{g kg}^{-1}$ in the Post-monsoon season [36].

3.3. Spatial Variation of Organochlorinated Residues in Sediment

The spatial variation of the concentrations of organochlorine pesticide residues in sediments from one site to another was observed in Lake Togo. The sediment samples, in which organochlorine residues were detected in high concentration, were rich in clay and organic matter contents. The highest concentration of organochlorine pesticide residues was detected in the sediments of three sites including Amedehoeve, Agomekpota and Kpessi. These results agreed with the sediment richness in clay and organic matter contents. It could be attributed to the fact that organochlorine molecules have greater tendency of binding to clay and organic matter known to influence the dynamics and behavior of both organic and inorganic pollutants in sediment by immobilization [37].

3.4. Seasonal Variation of Pesticide Residues Concentration in Water and Sediment

The results revealed a seasonal variation in the concentrations of the pesticide residues in water and sediment. They were higher during the dry season. The increased water levels during the rainy season may tend to lower the concentrations of the chemicals in the water column. Pesticide residues sorbed on the sediments may also be diluted by runoff during the rainy season. Thus like this, pesticide residues can be carried to away from Lake Togo by rainfalls. The results of the present study are in agreement with the findings of Hellar-Kihampa [27] who investigated pesticide residues in four rivers running through an intensive agricultural area in Tanzania. However, unlike our results, Abdullah et al. [26] found the highest amounts of HCHs, DDTs, endosulfans, endrin, and heptachlors in sediment during the rainy season.

They reported that pesticide usage was increased during the rainy season because pesticides were washed off more quickly and a higher amount of rainfall causes contamination from the soil because runoff water washes and releases pesticides bound to soil particles into water bodies particularly during the rainy season. Mazlan and Mumford [38] also pointed out that higher pest infestation in the rainy season caused higher consumption of pesticides.

4. Conclusion

This study assessed the levels of persistent chlorinated pesticides in sediment and surface water in Lake Togo. The concentration of organochlorine pesticide residues in water was lower than that of sediment samples. Results on water-sediments distribution pattern of the detected compounds reflect the high capacity of the lake sediments to adsorb and accumulate these compounds. The lake sediments act as a sink for the persistent contaminants. The results revealed also seasonal variation in concentration of organochlorine pesticides detected at the eight sampling sites and indicate the highest level residues in the dry season unlike those reported in previous studies. Pesticide pollution to the Lake Togo is therefore, likely to adversely affect human health in dry season. This study, while making a significant contribution to the knowledge of the contamination levels of water and sediment from Lake Togo, is still relatively spatially limited. Further studies covering the entire Togolese lagoon ecosystem including the lagoon of Vogan, the lagoon of Togoville and the lagoon of Aneho on fish, sediments and water are needed to better understand the level of contamination of all lagoon system.

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