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Assessment of organochlorine pesticides and polychlorinated biphenyls levels in fishes from the Volta lake, Ghana and their suitability for human consumption

Harriet Kuranchie-Mensah, Linda Maud Naa-Dedei Palm, Sampson Atiemo Manukure, Samuel Afful, Gladys Adjei-Martey and John Kwabena Arthur

Nuclear Chemistry and Environmental Research Centre, National Nuclear Research Institute, Ghana Atomic Energy Commission. Post Office Box LG 80, Legon-Accra.

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ABSTRACT

The levels of organochlorine pesticides and polychlorinated biphenyls were analyzed in four different fish species sampled from the Volta lake in Ghana. Fish muscles were subjected to soxhlet extraction for 16 h and further analysed by Gas Chromatography. The mean concentration of the HCHs, Drins, DDTs CHLs and HCB ranged from 4.03 to 13.04 ng/g; 3.46 to 12.29 ng/g; 7.96 to 38.05 ng/g; 4.55 to 39.62 ng/g and 0.34 to 1.21 ng/g respectively. *Chrysichthys nigrodigitatus*, *Clarias gariepinus*, *Oreochromis niloticus* and *Tilapia zilli* were the increasing order of magnitude of organochlorine pesticides detected among the species of fish. PCB concentration in the fishes ranged from a minimum of 0.90 ng/g to a maximum of 7.76 ng/g. The potential effect of contamination was assessed through the calculation of acceptable daily intake of organochlorines in the different fish species prescribed for human consumption. It was observed that the exposure of Ghanaian population through the consumption of fish from the Volta lake is relatively low and does not presently pose significant health risk.

Introduction

Organochlorine compounds (OCs) are group of chemicals characterized by their lipophilic nature, low chemical and biological degradation rates, accumulation in biological tissues and subsequent magnification of concentration in organisms progressing up in the food chain (Muralidharan, 2009). The ubiquitous and persistent nature of organochlorine compounds has resulted in the residue of these contaminants in different environmental and food matrices globally. Different aquatic resources particularly fishes originating from both marine and freshwater systems are being threatened by chemical pollution from these compounds. Generally the ability to metabolize organochlorines in fish is moderate, contaminant loading in fish therefore is well reflective of the state of pollution in surrounding environments (Fisk et al., 1998).

Since fishes are able to accumulate several fold higher concentration of organochlorine residues than the surrounding water (Siddiqui et al., 2005; Muralidharan, 2009), they have extensively been used for environmental monitoring which enables the assessment and transfer of pollutants through the food web (Lanfranchi et al., 2006; Sarkar, 2008). Exposure of organochlorines to humans is primarily through dietary intake (Davodi, 2011), while studies have shown that more than 80% of the total intake of pesticide residues in human beings is through the food chain (Martinez et al., 1997; Trotter and Dickerson, 1993; Mwevura et al., 2002). It has been reported that consumption of fish is a major contributor to dietary intake of organochlorines (Jiang et al., 2005; Llobet et al., 2008; Moon et al., 2009). Studies have also related the presence of organochlorine residues in breast milk and consumption of contaminated fish, and their role in alteration in thyroid function, endocrine and nervous system (Fitzgerald et al., 2001; Hagmar et al., 2001; Darnerud, 2003).

In Ghana, fish provide the consumer with almost 60% (Directorate of Fisheries, 2007) of their animal protein source studies have shown that the long chain omega-3 fatty acids have beneficial roles in human health (He et al., 2004; Ismail, 2005). Despite the benefit of fish consumption, fisheries resources continue to face significant challenge of chemical contamination worldwide (Siddiqui et al., 2005) and subsequent risk of exposure to these toxic chemicals on humans (Darnerud et al., 2006; Fattore et al., 2008; Sioen et al., 2008).

The Volta Lake from which this study was conducted is an extension of the River Volta which originates from Burkina Faso, Côte d'Ivoire and Togo (Adu-Kumi et al., 2010). Lake Volta has the largest surface area (8729 km^2) of any manmade lake in the world (Giesen, 2001) and a shoreline of 4800 km. It is the highest contributor of inland fisheries in Ghana accounting for about 80% of total catch (Directorate of Fisheries, 2007). Oreochromis niloticus, Chrysichthys nigrodigitatus, Tilapia zilli and *Clarias gariepinus* are some of the common species of fishes captured from the lake. These fishes are of high commercial value in Ghana and are consumed fresh, smoked or salted. Since the lake passes through agricultural fields, it is subjected to contamination with different pesticides used for crop protection mostly on cereals, cotton, coffee and other tubers (Ntow, 2005). Although studies in Ghana (Darko et al. 2008; Adu-Kumi et al., 2010) and other neighboring countries (Roche et al., 2006, Pazou et al., 2006) have revealed the presence of organochlorines in these fishes, however there is a dearth of information on the exposure and risk assessment of these contaminants to Ghanaian consumers through consumption of

Tele:
E-mail addresses: hettymens.k@gmail.com

these fishes. This study aims to examine the residue levels of freshwater fishes to enable an evaluation of exposure to organochlorine pesticides and polychlorinated biphenyls (PCBs) and subsequently assess the potential health risk from the consumption of individual fish species.

Materials and methods

Sampling and sample preparation

A total of 59 fishes were purchased from fishermen at a fish landing site along the bank of the Volta lake located at Kpong in the Eastern region of Ghana from January to August 2011. The fishes were wrapped in aluminum foils, kept on ice and immediately transported to the laboratory where it was prepared. The length and weight of the fishes were taken while the fillets were removed using stainless steel knifes and kept at – 20 ^{0}C until extraction.

Extraction and analysis of samples

Analysis of organochlorine compounds was performed according to procedure described by Therdteppitak & Yammeng (2003) and Kannan et al. (2008) with slight modification. All apparatus used in the study were precleaned and oven dried prior to analysis. Briefly, about 10 g of sample was subjected to soxhlet extraction for 16 h after it has been homogenized with 30 g unhydrous sodium sulfate (Hopkin and William Ltd England) and extracted with 300 ml hexane (95 + % purity, Sigma-Aldrich) and acetone (99.5 + %, BDH, England) (3:1 v/v). Prior to the extraction the sample was spiked with 100 µl of 100 ppb internal standard. The solvent was concentrated on a rotary evaporator after the extraction period to about 2 ml and subjected to cleanup using deactivated alumina (5 g, 8%). The sample was eluted with 40 ml hexane and further concentrated to 1 ml. The extract was fractionated over silica (1.8 g, 1.5%), the first fraction eluted with 10 ml hexane while the second fraction was eluted with hexane: diethyl ether (8.5: 1.5 v/v). fraction 1 contained all PCBs and some OCP (HCB) while fraction 2 contained the rest of OCPs.. The two fractions were concentration and picked in 1 ml iso-octane for GC analysis.

A gas Chromatograph Shimadzu 2010 coupled with electron capture detector was used determine the OCPs and PCBs. The conditions for the GC resolution are described as follows:

Oven program:

Initial temperature:	90 °C	Final temp 2:	265 °C
Initial time:	3 min	Final time 2:	5 min
Ramp 1:	30 °C/min	Ramp 3:	3 °C/min
Final temp 1:	200 °C	Final temp 3:	275 °C
Final time 1:	15 min	Final time 3:	15 min
Ramp 2:	5 °C/min	Total run time:	58 min

Injector settings:

Mode:	Pulsed splitless
Initial temp:	250 °C
Pressure:	1.441 bar
Pulse pressure:	4.5 bar
Pulse time:	1.5 min
Purge flow:	55.4 ml/min
Purge time:	1.4 min
Total flow:	63.5 ml/min

Column:

SGE BPX-5 (60 m x 0.25 mm x 0.25 µm) equipped with 1 m retention gap (0.53 mm, deactivated)

Detector settings:

ECD detector at 300 °C in "constant makeup flow" mode (30 ml/min of N_2)

Quality assurance/control

The quality of the study was assured through the analysis of standard solution and blank samples included in each batch of samples. Analysis of blanks did not contain traces of contaminants. One sample of each series was analyzed in three replicates. Recoveries of organochlorine pesticides and PCBs were achieved through the analysis of isodrin (OCPs) and PCBs (PCB # 112, PCB # 155, PCB #198) as internal standards added to each sample. Results of recoveries ranged from 78% to 95% for OCPs and 80% to 94% for PCBs.

Results and discussion

The types of species, body length and weight as well as the feeding behaviors of the fishes in this study are presented in Table 1. The organochlorine pesticides investigated were DDTs (o,p-DDT, o,p-DDE, o,p-DDD, p,p-DDE), HCHs (alpha-HCH, beta-HCH, gamma-HCH, delta-HCH); Drins (Aldrin, Dieldrin, Endrin); CHLs (trans-Chlordane, trans-Nonachlor, Heptachlor) and Hexachlorobenzene (HCB). The seven PCB congeners recommended by the European Union were analyzed in this study.

These are Polychlorinated biphenyl (PCB) congeners tri (28); tetra (52); penta (101, 118); hexa (138, 156) and hepta (180) were analyzed in the muscles of four fish samples from the Volta lake of Ghana (Table 2). All 15 organochlorine pesticides were detected in the four fishes except in *Oreochromis niloticus* and *Chrysichthys nigrodigitatus*. The residue levels of OCPs are present in varying amount in the species of fish sampled from the lake. Among the fishes, *Chrysichthys nigrodigitatus* recorded the highest Σ OCPs contaminant (mean concentration of 100.79 ng/g) followed by *Clarias gariepinus* (mean concentration of 40.75 ng/g), *Oreochromis niloticus* (mean of 33.59ng/g) and *Tilapia zilli* (mean of 20.34 ng/g). The concentrations of PCBs were detected at lower concentration compared to the OCPs. The difference in concentration of the fishes could be attributed to the feeding behavior of the fishes. *Chrysichthys nigrodigitatus* and *Clarias gariepinus* are carnivores fishes which are high of the tophic level and thus potential for bioaccumulation as compared to the *Oreochromis niloticus* and *Tilapia zilli* which are filter feeder primarily on phytoplanktons and algae.

Composition of ddts residues in the fishes

The mean Concentrations of DDT in the fish samples range from 0.71 to 15.95 ng/g (Table 2). Considering the isomers of DDT, o,p-DDD recorded the maximum mean concentration (15.95 ng/g) in all the fishes observed in *Chrysichthys nigrodigitatus* while o,p-DDT recorded the minimum of 0.71 observed in *Oreochromis niloticus*. Among all the fishes, *Chrysichthys nigrodigitatus* recorded the highest mean concentration of the DDT followed by *Clarias gariepinus* and *Oreochromis niloticus* with *Tilapia zilli* recording the least concentration. The composition of individual DDT isomers in the fishes are in the increasing order of o,p-DDT (6%) < p,p-DDE (27%) < o,p-DDE (31%) < o,p-DDD (35%), o,p-DDT (8%) < o,p-DDE (21%) <p,p-DDE (27%) < o,p-DDD (42%), o,p-DDE (10%) < o,p-DDT (13%) < p,p-DDE (22%) < o,p-DDD (56%) and o,p-DDT (9%) < o,p-DDE (31%) < p,p-DDE (21%) < o,p-DDD (53%) in *Oreochromis niloticus*, *Chrysichthys nigrodigitatus*, *Clarias gariepinus* and *Tilapia zilli* respectively (Figure 1).

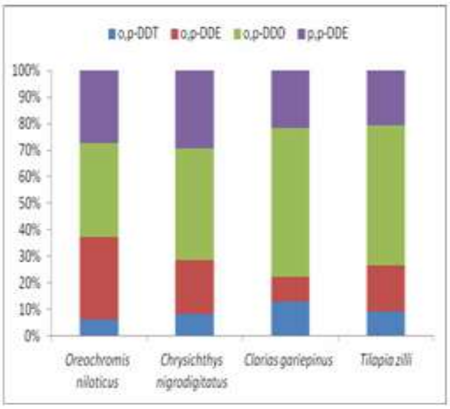

Figure 1: Percentage composition of DDT isomers in fish from the Volta Lake

With the exception of *Clarias gariepinus*, o,p-DDD was detected at higher concentrations than o,p-DDE and o,p-DDT signifying the metabolism of DDT in the fishes sampled from the Volta lake.

It has been studied that DDT deoxidized to DDD under anaerobic or reducing environment and oxidized to DDE in aerobic or oxidation environment (Guo et al., 2008; Hitch and Day, 1992). Among the p,p-DDTs, only the metabolite p,p-DDE were found in all the samples in the present study. Because of this only the ratios of o,p´-DDTs were calculated. It has been reported that the ratio of o,p´-DDD/ o,p´-DDE and o,p´-DDT/(o,p´-DDD + o,p´- DDE) can be used to assess the state of fish habitats, estimate the extent of DDT decomposition or identify recent inputs of DDTs into the ecosystem (Lee et al., 20011; Bordajandi et al., 2003; Guo et al., 2008). Among the individual species the ratio of o,p´-DDD to o,p´-DDE ranged from 1.1 to 5.9 in *Oreochromis niloticus* and *Clarias gariepinus* respectively and this could be correlated with past exposure of these species to DDT and low present input levels among the fishes. The ratio of o,p´-DDT to o,p´-DDE+o,p´-DDD in the fish samples was fairly similar among the samples. Oreochromis niloticus, Chrysichthys nigrodigitatus and Tilapia zilli recorded a ratio of 0.1 while the highest was recorded in Clarias gariepinus with ratio of 0.2. This confirms the earlier observation that the probability of fresh input of DDT in the lake is low and thus the presence of DDT could be correlated to the historical use of this pesticide in agricultural and for public health activity in the country.

Studies by Pazou et al. (2006) reports of concentration of p,p´-DDE as high as 26 folds in *Clarias gariepinus* and *Tilapia zilli* species from the Ouémé river, Benin and o,p´-DDT values 16 times higher in *Oreochromis niloticus* from the same river compared to value recorded in the current study. The concentration of ΣDDT in Tilapia zilli from the Volta lake were similar to values (8.88 ng/g) reported from Lake Bosumtwi by Darko et al. (2008) for the same species (Table 3).

Variation of HCHs residue among the fish species

All the isomers of HCHs were detected in all fish samples. In the study, the composition of isomers of HCH ranged from 0.72 ng/g to 4.38 ng/g, 1.02 ng/g to 4.17 ng/g, 0.40 ng/g to 10.29 ng/g and 0.41 ng/g to 1.72 ng/g in *Oreochromis niloticus*, *Chrysichthys nigrodigitatus, Clarias gariepinus* and *Tilapia zilli* respectively (Table 2). Delta-HCH recorded the highest concentration among all the isomers of HCH in the fish samples with relative abundance of more than 40% in all the fish samples. The highest mean concentration of beta-HCH (2.56 ng/g) and gamma-HCH (2.12 ng/g) were detected in *Chrysichthys nigrodigitatus* while a similar relative abundance of alpha-HCH was observed approximately 10% in the fishes. The abundance of gamma-HCH are in the decreasing order *Chrysichthys nigrodigitatus* (22%) > *Oreochromis niloticus* (19%) > *Tilapia zilli* (17%) > *Clarias gariepinus* (9%) (Figure 2). Compared to studies elsewhere the ΣHCH residue in the individual fishes are higher than those that have been reported by Monirith et al. (1999) (mean of 0.22 ng/g) from Cambodia, Sankar et al. (2006) (Mean of 0.72) from India, Chen et al. (2007) (0.028 ng/g) Jiangsu Province, China but less than work done by Kalyoncu et al. (2009) (32.6 ng/g) in Turkey (Table 3). HCHs generally contain the isomers in the following percentages: alpha-HCH 55–80%; beta-HCH 5-14%; gamma-HCH 8– 15%; delta-HCH 2–16%; with lindane containing more than 90% of gamma-HCH (Zi-wei et al, 2002). The variability of the isomers of HCHs detected in the samples could be attributed to the technical use of HCHs in the country and subsequently bioaccumulation of this contaminant in the aquatic environment.

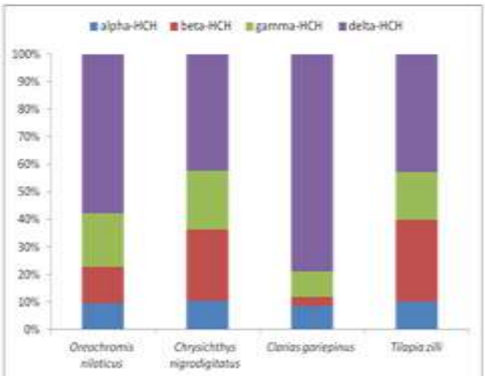

Figure 2: Percentage composition of HCH isomers in fish from the Volta Lake

Variation of drins in fishes

Although aldrin was detected in all samples, dieldrin and endrin was not detected in *Chrysichthys nigrodigitatus* and *Oreochromis niloticus* respectively. Aldrin, dieldrin and endrin concentration were found at moderate to high levels among the species. The mean concentration of aldrin varied in range from 1.36 ng/g to 8.63 ng/g with the maximum occurring in *Chrysichthys nigrodigitatus* and the minimum in *Oreochromis niloticus* (Table 2). The highest concentration of dieldrin was detected in *Oreochromis niloticus (*4.09 ng/g) followed by *Clarias gariepinus* (2.23 ng/g) and *Tilapia zilli* (0.64 ng/g). Concentration of endrin varied from not detected in *Oreochromis niloticus* to 1.18 ng/g in *Tilapia zilli*. The occurrence of endrin in *Clarias gariepinus* (3.37 ng/g) and *Chrysichthys nigrodigitatus* (3.66) were similar. The concentration of aldrin and dieldrin detected in *Tilapia Zilli* is about 4 and 2 folds respectively higher than what was reported by Darko et al. (2008) from lake Bosumtwi. Mean concentration of aldrin (11.5 ng/g and 13.6ng/g) and endrin (24.6ng/g and 7.17 ng/g) in *Oreochromis niloticus* and *Chrysichthys nigrodigitatus* reported from the waters of Lake Taabo in Cote d'Ivoire (Roche et al., 2006) are higher than the concentration recorded in this study.

Variation of chlordane and hcb in fish samples

The investigated chlordane compounds (CHLs) detected in the four fishes were trans-Chlordane, trans-Nonachlor and heptachlor with a mean concentration ranging from 4.55 ng/g to 39.62 ng/g *Chrysichthys nigrodigitatus* and *Tilapia zilli* respectively (Table 2). Trans-Chlordane was detected at a low concentration in the fishes while the highest CHLs detected was Heptachlor. The concentrations of heptachlor detected in the present studies were lower than what have been reported by Roche et al. (2006) in *Oreochromis niloticus* (7.36 ng/g) and *Chrysichthys nigrodigitatus (*35.6 ng/g) from lake Taabo in Cote d' Ivoire. However, CHLs results obtained in this studies is higher than values recorded in *Thynnichthys thynnoides* (0.09) and ng/g *Kryptopterus limpok* (0.03 ng/g) in Cambodia (Monirith et al., 1999) and *Parasilurus asotus* (0.03 ng/g) from Korea (Moon et al., 2009). Significantly different concentrations of HCB were observed among the different fishes. Compared to the CHLs, HCB were detected a low concentration with mean concentration varying from 1.21 ng/g >1.01 ng/g > 0.96 ng/g >0.34 ng/g in *Clarias gariepinus, Oreochromis niloticus, Chrysichthys nigrodigitatus* and *Tilapia zilli* respectively. Adu-Kumi et al. (2010) reported of an average concentration of HCB in tilapia and catfish sampled from lake Volta, Bosumtwi and Weija in Ghana. This indicates generally low HCB levels in freshwater fishes in Ghana. HCB was used as fungicide for seed treatment prior to its ban and could also be generated as a by-product in the manufacturing processes of various chlorine-containing chemicals. Additionally it has been found as an impurity in several pesticides (Naso et al., 2005; Bailey, 2001) and thus its presence in the fishes could be attributed to these sources.

Variation of PCB congeners among the fish species

PCB # 28 and 52 were the predominant congeners observed among the PCBs accounting for 58% and 60% respectively. PCB # 138 were detected in only two of the fishes while that of PCB congener 180 was not detected in any of the samples analyzed. The contribution of each PCB to the total PCBs in the fishes were almost the same. PCBs congener 52 recorded both the highest and least concentration observed in *Chrysichthys nigrodigitatus* and *Oreochromis niloticus* respectively. The total concentration of PCBs among the fishes was in the increasing order of *Chrysichthys nigrodigitatus* (12.36 ng/g) Clarias gariepinus (7.76 ng/g) Tilapia zilli (2.43 ng/g) and Oreochromis niloticus (0.90 ng/g) (Figure 3).

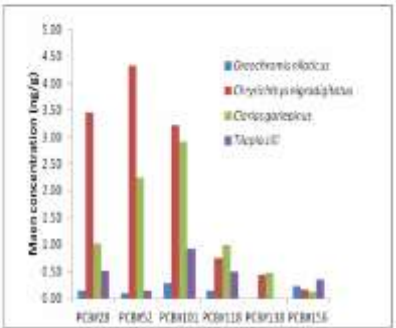

Figure 3: Mean concentration of PCB congener in fish from the Volta Lake

The PCB levels in the current study are however higher than values reported by Monirith et al. (1999) from Cambodia and Moon et al. (2009) from Korea in different fish species (Table 3). The bioconcentration of PCBs in aquatic organisms correlates with the degree of chlorination, the stereochemistry, and lipophilicity (Bordajandi et al., 2003). The reason for generally low concentration of PCBs in the fish samples could be attributed to the fact that, the less chlorinated homologues have a lower logKow as compare to the more chlorinated congeners. They therefore have a lower propensity to leave the aqueous environment for organic compartments and thus when present in organisms, they are usually more rapidly metabolized than the higher chlorinated congeners because of the presence of more unsubstituted ring positions on their biphenyl rings available for the metabolic attack (Naso et al., 2005, Gray, 2002).

Assessment of potential health risk through dietary intake of OCPs and PCBs

The health effect of organochlorine pesticides cannot be underestimated and thus maximum residue limits has been recommended by various agencies to regulate human consumption of these chemicals (Sankar et al., 2006). Residue levels of organochlorines in all fish samples analyzed in this study are considerably below the respective maximum residue limits set by EU, Italian, FDA and FAO (Table 4). The dietary intake of OCPs and PCBs were calculated by multiplying the chemical concentrations measured in each species by the rate of consumption of fish estimated at 68.5 g/day (Global Fish Alliance, 2010). The estimated dietary intake of OCPs and PCBs in the fishes analysed in this study is summarized in (Table 5). The dietary intake of HCHs, DDTs, Drins, CHLs, HCB and PCBs were 2.37, 4.75, 2.02, 4.04, 0.24 and 1.61 ug/person/day respectively. The consumption of *Chrysichthys nigrodigitatus* (7.77 ug/person/day) among the fishes happens to be the highest risk of exposure OCPs to Ghanaian followed by *Clarias gariepinus* (3.31 ug/person/day) *Oreochromis niloticus (*2.37 ug/person/day) and the least risk of exposure is through the consumption of *Tilapia zilli* (1.58 ug/person/day) *(*Figure 4).

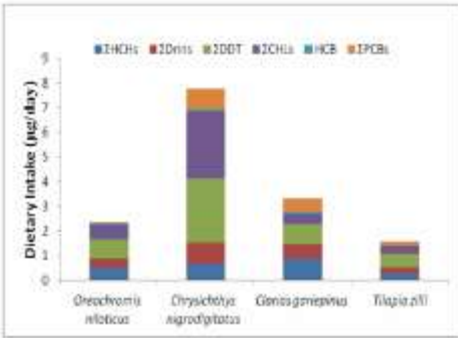

Figure 4: Estimated dietary intake (µg/person/day) of organochlorine compounds through the consumption of Oreochromis niloticus, Chrysichthys nigrodigitatus, Clarias gariepinus and Tilapia zilli from the Volta Lake

The estimated daily intake of in this study are higher than those reported by Moon et al. (2009) from South Korea and Stefanelli et al. (2004) from Italy which exposes Ghanaian consumers to high risk. Meanwhile the daily intake of DDTs was lower than those reported by Pazou et al. (2006) in the Queme river in Benin for the same species of fish. Considering the health effects on humans, the calculated daily intake for HCHs and DDTs are well below limits set by Health Canada (1996) (18 µg/person/day) and International Agency for Research on Cancer (1989) (300 µg/person/day) respectively. It could be concluded that exposure of humans through fish consumption from the Volta lake do not appear to be harmful presently although chronic exposures could lead to serious health problems. The body burden of organochlorine pesticides has been associated with various health problems and thus the presence of these chemicals in the diet of Ghanaians call for concern although the levels are below the acceptable daily intake. It is thus appropriate to ensure that systematic measure and continuous monitoring are implemented to curtail any accelerated levels of these toxicants in the waters of Ghana.

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Table 1: Biometric data of fishes included in this study

Scientific Name (Common name)	Number of samples	Length (cm) Range	Length (cm) Mean ± StDev	Weight (g) Range	Weight (g) Mean ± StDev	Feeding Habit[a]
Tilapia zilli (Redbelly tilapia)	14	27.7 - 29.2	28.5 ± 0.755	412.95 - 515.3	463.83 ±51.178	Phytoplanktons, detritus, algae
Oreachromis niloticus (Nile tilapia)	14	24.3 - 26.4	25.375 ± 0.918	216 - 341.5	284.4575 ± 58.132	Phytoplanktons, detritus, algae
Chrysichthys nigrodigitatus (Silver catfish)	16	31.4 - 36.4	34.1 ±2.523	247.63 - 409	316.703 ± 83.154	Fish, insects, crustaceans, mollusk, worms, rotifers and plant materials, detritus
*Clarias gariepinus North (*African catfish)	15	41.5-46.7	44.3 ± 3.7	505.85 - 712.8	534.6 ± 46.37	Zoobenthos, insects, crustaceans, mollusk, worms, rotifers, detritus

Source: [a]Fish Base, 2011

Table 2: Concentrations of organochlorine compounds in fish from the Volta Lake (ng/g wet weight)

Name of OC compound	*Oreochromis niloticus*		*Chrysichthys nigrodigitatus*		*Clarias gariepinus*		*Tilapia Zilli*	
	Range	Mean ± StDev	Range	Mean ± StDev	Range	Mean ± StDev	Range	Mean ± StDev
OCPs								
alpha-HCH	0.28-1.17	0.72±0.44	0.59-1.51	1.02±0.46	0.31-2.40	1.12±1.11	0.14-0.71	0.41±0.28
beta-HCH	0.49-1.54	1.00±0.52	0.36-4.18	2.56±1.97	0.35-0.47	0.40±0.06	0.96-1.49	1.20±0.27
gamma-HCH	0.57-1.99	1.47±0.79	1.00-3.21	2.12±1.10	1.11-1.32	1.22±0.11	0.51-0.84	0.70±0.17
delta-HCH	2.13-8.78	4.38±3.82	1.83-5.70	4.17±2.06	1.96-25.70	10.29±13.36	0.75-3.16	1.72±1.27
Heptachlor	2.74-6.34	4.03±2.00	5.09-19.92	13.56±7.64	1.28-7.57	4.28±3.16	0.36-6.34	2.64±3.23
Aldrin	0.46-1.91	1.34±0.78	4.91-13.33	8.63±4.29	0.33-6.20	2.76±3.06	1.45-1.81	1.64±0.18
Dieldrin	3.45-4.75	4.09±0.65	<LOD	<LOD	0.87-3.37	2.23±1.27	0.30-1.00	0.64±0.35
Endrin	<LOD	<LOD	2.70-4.63	3.66±0.96	3.34-3.42	3.37±0.04	0.90-1.41	1.18±0.26
o,p-DDT	0.66-0.73	0.71±0.04	2.11-3.87	3.09±0.90	0.23-2.90	1.47±1.34	0.60-0.84	0.73±0.12
o,p-DDE	1.32-5.56	3.59±2.13	5.37-9.30	7.81±2.13	0.85-1.46	1.10±0.32	1.24-1.56	1.37±0.16
o,p-DDD	4.01-4.20	4.08±0.11	12.59-17.97	15.95±2.93	0.27-15.70	6.52±8.12	4.04-4.40	4.21±0.18
p,p-DDE	0.93-6.17	3.15±2.71	8.91-12.72	11.19±2.01	2.15-2.97	2.52±0.42	0.93-2.34	1.65±0.70
trans-Chlordane	0.13-0.15	0.14±0.01	10.12-15.99	13.39±2.99	0.15-0.26	0.20±0.05	0.15-0.30	0.23±0.07
trans-Nonachlor	1.70-6.38	3.89±2.35	10.07-14.24	12.67±2.27	0.87-3.59	2.05±1.40	0.87-2.59	1.69±0.86
HCB	0.18-1.51	1.01±0.72	0.80-1.10	0.96±0.15	1.09-1.34	1.21±0.13	0.24-0.42	0.34±0.09
PCBs								
PCB#28	0.11-0.18	0.15±0.03	0.92-6.09	3.46±2.59	0.92-1.09	1.02±0.09	0.48-0.52	0.49±0.02
PCB#52	0.04-0.13	0.09±0.05	2.73-7.08	4.33±2.40	1.28-3.17	2.24±0.95	0.00-0.15	0.09±0.08
PCB#101	0.24-0.34	0.29±0.07	2.01-4.84	3.22±1.46	2.69-3.23	2.91±0.29	0.79-0.93	0.86±0.07
PCB#118	0.08-0.22	0.15±0.07	0.33-0.99	0.75±0.37	0.79-1.23	0.98±0.22	0.32-0.49	0.42±0.09
PCB#138	<LOD	<LOD	0.26-0.61	0.44±0.18	0.18-0.66	0.48±0.27	<LOD	<LOD
PCB#156	0.16-0.26	0.23±0.06	0.09-0.25	0.17±0.08	0.09-0.20	0.13±0.06	0.17-0.35	0.24±0.09

Table 3: Comparison of OCs concentration in fish from Lake Volta to reported data worldwide

Species	Common Name	Location	DDTs	HCBs	CHLs	HCHs	PCBs	Aldrin	Dieldrin	Endrin	Reference
Thynnichthys thynnoides	White lady carp	Kompong Chhnang, Cambodia	1.9	0.32	0.09	0.22	0.17	-	-	-	Monirith et al., 1999
Kryptopterus limpok	Whisker sheatfish		3.4	0.03	0.03	0.03	0.17	-	-	-	
Puntioplites proetozysron	Smith barb		11	0.01	0.15	0.07	0.16	-	-	-	
Mastocembelus armatus	Arm spiny eel		8.2	0.06	0.24	0.16	0.16				
Notopterus notopterus	Grey featherback	Kompong Cham, Cambodia	3.2	0.05	0.07	0.05	0.16	-	-	-	
Lutra lutra	Otters	Droˆme (France)	-	-	-	-	7.8–56.9	-	-	-	Mazet et al., 2005
Scatophagus argus		Calicut fish landing center, India	6.91	-	-	0.72	-	-	-	-	Sankar et al., 2006
Oreochromis niloticus	Nile tilapia	Ouémé river, Benin	129	-	-	-	-	-	-	-	Pazou et al., 2006
Clarias gariepinus	North African catfish		535	-	-	-	-	-	-	-	
Tilapia zilli	Redbelly tilapia		134	-	-	-	-	-	-	-	
Chrysichthys nigrodigitatus	Silver catfish		196	-	-	-	-	-	-	-	
Grass Carps	Grass carps	Jiangsu Province, China	0.66	-	-	0.028	-	0.018	0.035	-	Chen et al., 2007
Oreochromis niloticus	Nile tilapia	Lake Taabo, Cote d'Ivore	124.1	-	93.91	206	-	11.3	-	24.6	Roche et al., 2007
Chrysichthys nigrodigitatus	Silver catfish		94.6	-	64.55	275	-	13.6	-	7.17	
Tilapia zilli	Redbelly tilapia	Lake Bosumtwi, Ghana	8.877	-	-	0.126	-	0.35	0.420	-	Darko et al., 2008
Parasilurus asotus	Catfish	Busan fish market, Korea	0.12	0.05	0.03	<0.02	0.57	-	-	-	Moon et al., 2009
Mullus barbatus	Red mullet	Konya market, Turkey	43.7	-	16.9	31.700	-	3.300	2.800	6.900	Kalyoncu et al., 2009
Trachurus trachurus	Horse mackerel		60.6	-	26.6	32.6	-	16.1	12.6	32.63	
Tilapia zilli	Redbelly tilapia	Lake, Bosumtwi, Weija, Volta	28.68- 253.59	0.08- 4.20	3.52 -17.70	<LOD		-	-	-	Adu-Kumi et al., 2010
Clarias spp.			2205.50-47.53	1.80 -2.90	1.90-6.28	0.60-0.83		-	-	-	
Oreochromis niloticus	Nile tilapia	Volta Lake, Ghana	11.52	1.01	8.06	7.57	0.902	1.34	4.09	-	This study
Chrysichthys nigrodigitatus	Silver catfish		38.05	0.961	39.6	9.87	12.4	8.63	-	3.66	
Clarias gariepinus	North African catfish		11.61	1.21	6.53	13.04	7.76	2.764	2.23	3.37	
Tilapia zilli	Redbelly tilapia		7.957	0.34	4.55	4.03	2.43	1.64	0.637	1.19	

Table 4: Comparison of mean concentration of OCPs and PCBs to Maximum Residue Limits (MRLs) stipulated by various statutory agencies

Compound	EU MRL (mg/kg)[a]	Italian MRL (ng/g)[a]	FDA, 2001 (mg/kg)[b]	FAO, 1983 (mg/kg)[b]
ΣChlordane	0.05	50		
ΣDDT	1	1000	5	0.3
dieldrin	0.2	200	0.3	0.3
ΣHeptaclor	0.2	200	0.3	0.3
HCB	0.2	200		
alpha-HCH	0.2	200		
beta-HCH	0.1	100	0.3	0.3
gamma-HCH	1	1000	0.3	0.3
Endrin	0.05	50	0.3	0.3
ΣPCB	0.2			

Stefanelli et al., 2004; [b]Sankar et al., 2006

Table 5: Estimated daily intake (µg/person/day) of OCs assessed for fish consumption by the general population of Ghana

Name of OC compound	*Oreochromis niloticus*	*Chrysichthys nigrodigitatus*	*Clarias gariepinus*	*Tilapia zilli*
OCPs (µg/person/day)				
alpha-HCH	0.05	0.07	0.08	0.03
beta-HCH	0.07	0.18	0.03	0.08
gamma-HCH	0.1	0.15	0.08	0.05
delta-HCH	0.3	0.29	0.7	0.12
Aldrin	0.09	0.59	0.19	0.11
Dieldrin	0.28	-	0.15	0.04
Endrin	-	0.25	0.23	0.08
o,p-DDT	0.05	0.21	0.1	0.05
o,p-DDE	0.25	0.54	0.08	0.09
o,p-DDD	0.28	1.09	0.45	0.29
p,p-DDE	0.22	0.77	0.17	0.11
trans-Chlordane	0.01	0.92	0.01	0.02
trans-Nonachlor	0.27	0.87	0.14	0.12
Heptachlor	0.28	0.93	0.29	0.18
HCB	0.07	0.07	0.08	0.02
PCBs (µg/person/day)				
PCB#28	0.011	0.237	0.069	0.035
PCB#52	0.006	0.296	0.153	0.010
PCB#101	0.019	0.220	0.199	0.063
PCB#118	0.010	0.051	0.067	0.033
PCB#138	-	0.030	0.033	-
PCB#156	0.015	0.012	0.009	0.023