

Persistent organochlorine compounds in the water and sediment samples from the Lake Bosomtwe in Ghana

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ABSTRACT

Aims: To investigate the burden of organochlorine pesticides (OCPs) and its degradation products as well as indicator polychlorinated biphenyl (PCBs) in the water and sediments of the Lake for the purpose of broadening the knowledge on organochlorine pollution of the Lake.

Study design: This investigation involved one year monitoring of the Lake for the purpose of assessing organochlorine pesticides as well as indicator PCBs. Samples were collected three times during dry, wet and minor wet seasons within the study period.

Place and Duration of Study: Lake Bosomtwe was the study area and analysis of samples was carried out at the Nuclear Chemistry and Environmental Research Centre of Ghana Atomic Energy Commission from January 2012 to February 2013. Sampling was done three times within the study period.

Methodology: Liquid-liquid extraction with hexane was used for the water samples while sediment samples were sonicated in ultrasonic bath with hexane/acetone mixture (3:1). The extracts were then cleaned up with florisil and quantified on a micro-capillary gas chromatography equipped with electron capture detector.

Results: Eight OCPs and four indicator PCBs were detected in Lake waters while sixteen OCPs and five indicator PCBs were detected in the sediments. The mean concentrations of OCPs ranged from 0.05 to 6.35 ng/ml for the water samples and ranged from 0.05 to 15.23 ng/g for the sediments. The total PCBs load (sum of all indicator PCBs) also ranged from 1.09 – 7.19 ng/ml and 6.43 – 19.17 ng/g for the water and sediments respectively.

Conclusion: The study has shown that organochlorine compounds are present in the Lake Bosomtwe in Ghana. The detection of organochlorine pesticides in waters and sediments could be attributed either to historical use of these chemicals for agricultural purpose or environmental transport of these chemicals to the study area. The presence of some indicator polychlorinated biphenyls could also be attributed to leakages to release to the environment during various anthropogenic processes such as incineration, combustion, smelting and leakages from refuse dumps containing dumped transformers and capacitors. More organochlorine compounds were detected in the sediments compared to the water samples. Sediments may therefore serve as sink for organochlorine compounds.

18 *Keywords: Keywords: persistent organochlorine, detected, lake, bosomtwi, sediment, water*

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21 **1. INTRODUCTION**

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23 Africa in the past was considered to be safe from water body pollution. However, the high
24 anthropogenic activities have resulted in a remarkable amount of pollutants and diversity of
25 discharges that are reaching our aquatic environment. Water body pollution may result from
26 a variety of sources. Common sources of water body pollution include oil spillage, wastes
27 dumped into water bodies, and run off from agricultural and industrial sites. Oil spillage
28 harms river mammals. Wastes such as plastic bags, fishing nets and other trash items which
29 are dumped can accumulate in an area and entangle water body mammals. This can lead to
30 their death. Run-off from agricultural sites may introduce pesticides residues or fertilizers into
31 the water bodies. Pesticides contamination leads to fish kill, while fertilizer pollution results in
32 algal blooms that choke naturally occurring plants. These eventually reduce the diversity of
33 organisms in water bodies [1].

34 For some time now pollutants in the environment which have generated international
35 concern is persistent organic pollutants [2] in which organochlorine compounds are the
36 dominant pollutants among others. Persistent organochlorine pollutants are organic
37 compounds that, to a varying degree, resist photolytic, biological and chemical degradation
38 [3]. They are chlorinated compounds with carbon-chlorine bond(s). They are characterized
39 by low water solubility and high lipid solubility. Exposure of persistent organochlorine
40 compounds such as polychlorinated biphenyls (PCBs), DDTs, hexachlorohexanes (HCHs),
41 hexachlorobenzene (HCB) has been linked to range of conditions including reproductive
42 toxicity, immunotoxicity, hepatotoxicity, neurotoxicity, necrosis and endocrine abnormalities [4].
43 They are semi-volatile, and this enables them to move long distance in the atmosphere
44 before deposition [5]. Evidence available indicates that because they are able to undergo
45 long range environmental transport, they may be found in areas where they have never been
46 produced or used. The high lipid solubility and stability of organochlorine compounds have

47 resulted in their widespread distribution in nearly all environmental compartments such as in
48 air, water bodies, rain, soil and biota. The lipophilic nature of organochlorine has led to their
49 bioaccumulation and biomagnification in living organisms including fishes, humans and other
50 animals. Although many different forms of organochlorine compounds may exist, both
51 natural and anthropogenic, those which are noted for their persistence and bioaccumulative
52 characteristics include PCBs, many of the first generation organochlorine insecticides,
53 toxaphenes and dioxins.

54 Persistent organochlorine compounds such DDTs, HCHs, HCB, endosulfan and PCBs had
55 been used in the past in Ghana. PCBs was used as dielectric fluid in transformers and
56 capacitors by Electricity Company of Ghana and Volta River Authority and DDTs, HCHs,
57 HCBs, endosulfan was used as pesticides in Ghana. Other organochlorines are used in
58 industrial processes and in the production of a range of goods such as solvents, polyvinyl
59 chloride and pharmaceuticals [5]. Many congeners of PCBs are formed and released to the
60 environment during various anthropogenic processes such as incineration, combustion,
61 smelting and metal reclamation [6, 7].

62 As a result of persistency and toxicity of organochlorine compounds, there is currently an
63 international effort under the Stockholm Convention aimed at total elimination of PCBs by
64 2025 [4]. In Ghana's effort of achieving the goals set by the Convention, the Environmental
65 Protection Agency (EPA) has banned the use of these organochlorine pesticides in Ghana.
66 In the case of PCBs, PCB containing equipment requires that all dielectric fluids from
67 transformers and capacitors are tested to ensure that PCBs of concentrations is not greater
68 than 50 µg/g [4].

69 In Ghana, Lake Bosomtwi is among the important water resources that the nation can boast
70 of. It is the only natural Lake in Ghana, and situation about 30 km south east of Kumasi. The
71 local community dotted around the Lake use it mainly for fishing, swimming and boat

transport. The water from the Lake is also used for cooking and washing. There is no doubt that the Lake has received some amount of pollution as a result of these anthropogenic activities along and outside the Lake. Indeed, studies on the quality of water bodies in Ghana had focused mainly on physico-chemistry, nutrient burden, trace metals and pesticide residues contamination [1, 8, 9]. Studies in Ghana and other neighboring countries [10, 11] have revealed the presence some organochlorine compounds in our environment. Indeed, Darko et al (2008) studied organochlorine pollution of the Lake Bosomtwi. Their investigation was however, limited in scope as it focused only on few pollutants such as γ - HCH, DDT, DDE, aldrin, dieldrin, and endrin. The study failed to address the most degradation products formed in the environment by these compounds. Typical organochlorine compounds such as indicator PCBs were not studied. This present study therefore seeks to provide a broader knowledge on organochlorine pollution of the Lake. In this investigation the burden of organochlorine pesticides and its degradation products as well as indicator PCBs in the water and sediments of the Lake are investigated. With respect to PCBs, the study focused only on indicator PCBs since they are known to be persistent in the environment and bioaccumulate in food chain. They are assumed to be representative for all PCBs.

2. METHODOLOGY

2.1 The study area

Lake Bosomtwi, shown in figure 1 is situated within an ancient meteorite impact crater. It is approximately 8 km across and the only natural Lake in Ghana [12]. The Lake has a coordinate of 6° 30.31'N 1° 02.45' W with a catchment area of 400 km². Lake Bosomtwi has maximum length of 8.6 km, maximum width of 8.1 km and surface area of 49 km². There are about 30 villages dotted around the lake, with a combined population of about 70,000 people. The Ashanti consider Bosomtwi a sacred Lake. According to traditional belief, the souls of the dead come here to bid farewell to the god Twi. Because of this, it is considered permissible to fish in the lake only from wooden planks. Lake Bosomtwi is a natural inland

101 freshwater Lake in the Ashanti Region of Ghana. The Lake exhibits a radial drainage system
102 of 106 km², a diameter of about 11 km at its widest part and a maximum depth of 78 m. Lake
103 Bosomtwi covers an area of about 52 km² [13]. The most important controls on the water
104 balance of the lake are rainfall directly onto, and water evaporating directly from, the surface
105 of the lake. It is reasonable to assume, when considering the hydrogeological conditions that
106 little or no groundwater enters or leaves the basin. The Lake is one of the main sources of
107 livelihood for the communities living around and they heavily depend on the fish catch for
108 their income and food (protein). Besides fishing, they depend on the aquatic resource for
109 cooking, washing and irrigation water for agricultural activities. The Lake also provides the
110 basis for other social and economic opportunities such as transportation and tourism. The
111 Bosomtwi forest reserve, which is near the Ankaase community at Lake Bosomtwi, has an
112 area of 140 km², is a legally protected area consisting of semi-deciduous tropical rainforest
113 and provides a typical natural environment which attracts eco-tourism.

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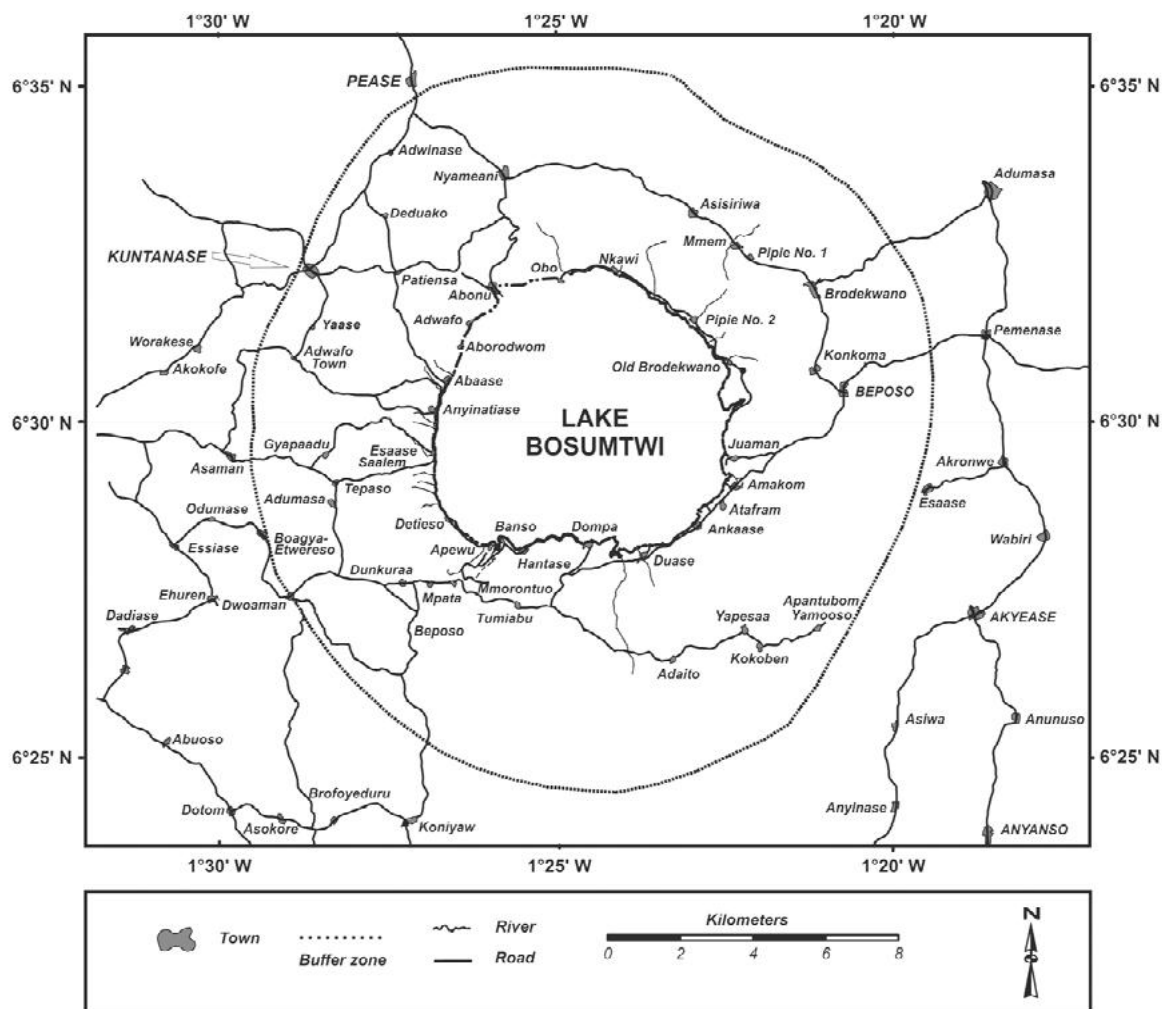


Figure 1: Map of Lake Bosomtwi and the sampling locations

2.2 Chemicals and reagents

All chemicals and reagents used for the investigation were of high purity and they were analytical grade. Hexane (96+%), acetone (99 %), ethyl acetate (99.8%), anhydrous sulphate were purchased from Sigma-Aldrich, Germany. Florisil adsorbent was purchased from Hopkins and William Limited, England. The organochlorine standards were from United Nation environmental Programme (UNEP).

125 **2.2 Sampling and sample preparation**

126 Water and sediment samples were collected from **ten** communities dotted around the Lake.
127 The ten sampling points stretches from Pipie 2 to Esaase. At each point three water and
128 sediment samples were collected. Surface water samples were collected into 500 ml high-
129 density polyethylene containers. Sediment samples were collected at various points in the
130 neighborhood where the water samples were collected using Eckman grab from a depth of
131 about 20 cm. All samples were stored in an ice-chest and transported to the laboratory. In
132 the laboratory the water samples were kept in fridge at a temperature of about 40C and the
133 sediment samples were dried at room temperature. The sediments were then milled with
134 pestle and mortar and sieved with 500 µm mesh size sieve to remove stones and other
135 debris. The sieved samples were then kept at room temperature in a clean cupboard.

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137 **2.3 Extraction of organochlorine compounds (OCs) from samples**

138 Liquid-liquid extraction with hexane was used for the extraction of the extractable
139 organochlorine from the water samples. Twenty ml portion of the water sample was shaken
140 with 20 ml of hexane as extraction solvent in 100 ml separating funnel. Extract was then
141 concentrated on rotary evaporator and then subjected to clean up. Organochlorines were
142 extracted from the sediments by sonicating on an ultrasonic bath (Branson 220, Branson
143 Ultrasonic Cleaner, USA) for 2 hours at 40 °C with 3:1 hexane/acetone solvent system. After
144 filtration, the filtrate was passed over copper turnings to remove any extractable
145 organosulphur compound. Extract was concentrated on rotary evaporator and subjected to
146 clean up.

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149 **2.4 Clean up of extracts**

150 The clean up procedure was carried out according to the method of Nyarko et al [14]. After
151 loading the column with the extract, it was eluted first with 10 ml hexane followed by with 5
152 ml of 1: 2 hexane/diether. The eluate was concentrated to almost dryness by blowing in
153 stream of nitrogen gas and residue re-dissolved in 1.5 ml ethyl acetate. The final extract was
154 transferred quantitatively into 2 ml vial for GC analysis.

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156 **2.5 Gas chromatography (GC) analysis**

157 A Varian CP-3800 Gas Chromatograph equipped electron capture detector was used for
158 analysis. A volume of 1µl aliquots of sample extract was injected. The operation conditions
159 were capillary column: VF – 5mS, 40m x 0.25mm x 0.25µm, temperature programme: 700C
160 (2min) to 1800C (1min) 250C/min to 3000C at 50C/min, injector temperature: 2700C,
161 detector temperature: 3000C, carrier gas: nitrogen at 1.0ml/min, make up: nitrogen at
162 29ml/min. The organochlorines were identified based on comparison of relative retention
163 times to those of known standards and quantified by external standard method using peak
164 area.

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166 **2.6 Quality assurance/control**

167 The quality of the study was assured through analysis of standard solutions and blank
168 samples included in each batch of analysis. Analysis of blanks did not contain traces of the
169 pollutants. Recovery studies involving analysis of spiked samples with organochlorine
170 standards were carried out and percentage recoveries were between 96.0 – 101.0 %. The
171 GC-ECD method used for the studied was also validated with certified reference material

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173 3. RESULTS AND DISCUSSION

174 3.1 Mean concentrations of organochlorines compounds in the samples

175 Tables 1 and 2 respectively, show the mean concentrations of detected organochlorine
176 compounds in the water and sediments from sampled from January 2012 to February 2013.
177 Margins of errors are standard deviation based on triplicate determination of each
178 compound. The Tables also show the percentage occurrence for each compound in the
179 study area. Analysis of the water samples revealed the presence of eight persistent
180 organochlorine pesticides and four indicator PCBs. With respect to the sediments, sixteen
181 persistent organochlorine pesticides and five indicator PCBs were detected. The studied
182 compounds in both water and sediment samples were α -HCH, β -HCH, δ -HCH, γ -HCH,
183 heptachlor, aldrin, γ -chlordane, α -endosulfan, p,p¹-DDE, dieldrin, endrin, β -endosulfan, p,p¹-
184 DDD, P,P-DDT and methoxychlor, PCB 28, PCB 52, PCB 101, PCB 138, PCB 153 and PCB
185 180. The concentrations of the compounds, β -HCH, α -HCH, aldrin, δ -chlordane, α -
186 endosulfan, PCB 28 and PCB 153 were below detection limit at some of the sampling
187 locations. The limit of detection (LOD) is defined as the lowest practical concentration of the
188 contaminant that can be identified and quantitatively measured in a specific matrix [15]. This
189 was estimated as concentration which peak was three times the peak of signal to noise ratio.
190 The trends of persistent organochlorine compounds distribution in the samples indicate
191 higher organochlorine concentrations in sediments than in the water. In an aquatic medium,
192 persistent organochlorine compounds being hydrophobic tend to settle more in sediments
193 than remain in the overlying water. Sediments therefore serve as sink for persistent
194 organochlorine compounds. The mean concentrations of organochlorine pesticides and
195 PCBs in sediments ranged from 0.05 – 15.23 ng/g and 0.16 – 10.50 ng/g respectively. Darko
196 et al (2008) similarly reported higher concentrations of organochlorine pesticides in
197 sediments than in waters from Lake Bosomtwi [8].

198 Table 3 compared the results of the present study to Darko et al (2008) and Rochel et al
199 (2007)[10]. It is clear from the studies that Darko et al (2008) investigation was limited in
200 scope as it focused only on few organochlorine pesticides. This study has shown that
201 degradation products such as p, p¹ - DDE, p, p¹ - DDD, and endosulfan sulfate are some of
202 the organochlorine metabolites present in the Lake. The present study has further brought to
203 the fore that other organochlorine compounds can be found in the Lake. Rochel et al
204 (2007)[10] on the other hand, results show higher organochlorine concentrations in Lake Taabo in Cote
205 d'Ivoire compared to this study.

206 The sources of organochlorine pesticides in the Lake Bosomtwi could be attributed to
207 historical use of these chemicals by farmers while the present of indicator PCBs could
208 possibly be linked to release to the environment during various anthropogenic processes
209 such as incineration, combustion, smelting and metal reclamation [6, 7]. Leakages of PCBs
210 from dumped decommissioned transformers and capacitors into landfills in the past could
211 also be sources of PCBs congeners to the Lake. However, nowadays, when these electrical
212 units are decommissioned, their PCB content is stored to prevent further contamination. In
213 all PCB 52 was the most ubiquitous organochlorine compound in the water while γ -HCH,
214 endrin and PCB 52 were the most ubiquitous compounds in the sediments, also with
215 hundred percent occurrences. The ubiquity of PCB 52 in the present study might be
216 attributed to its persistency in the environment compared to the other indicator PCBs.

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218 Table 1: Concentration of detected organochlorines (mean $\pm$ SD in ng/ml) and percentage occurrence in water from Lake Bosumtwi

[illegible]

PCB 52	4.47±0.55	1.09±0.2	3.62±0.61	4.13±0.99	1.68±0.40	0.75±0.06	1.99±0.13	4.72±0.03	4.26±0.33	1.81±0.11	100
PCB 101	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02±0.002	<0.01	<0.01	<0.01	10
PCB 153	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0
PCB 138	<0.01	<0.01	0.12±0.02	<0.01	<0.01	<0.01	<0.01	1.15±0.02	<0.01	<0.01	20
PCB 180	<0.01	<0.01	<0.01	3.06±0.81	<0.01	0.51±0.03	<0.01	<0.01	<0.01	<0.01	20
Σ PCBs	4.47±0.55	1.09±0.2	3.74±0.63	7.19±1.80	1.68±0.40	1.26±0.09	2.01±0.13	5.87±0.05	4.26±0.33	1.81±0.11	100

222 % occ = percentage occurrence

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244 Table 2: Concentration of detected organochlorines (mean $\pm$ SD in ng/g) and percentage occurrence in sediments from Lake Bosomtwi

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<u>Compounds</u>	<u>Sampling points</u>										% occ
	Esaase	Anyinatiase	Abaase	Aborodwom	Obo	Nkawi	Pipie 2	Brodekwano	Abonu	Adwafo	
β -HCH	<0.01	0.05 $\pm$ 0.01	0.05 $\pm$ 0.01	<0.01	<0.01	<0.01	0.50 $\pm$ 0.02	0.05 $\pm$ 0.01	<0.01	<0.01	40
α -HCH	0.15 $\pm$ 0.02	1.15 $\pm$ 0.03	<0.01	<0.01	0.50 $\pm$ 0.02	<0.01	0.22 $\pm$ 0.04	<0.01	<0.01	<0.01	40
δ -HCH	<0.01	0.15 $\pm$ 0.07	0.40 $\pm$ 0.01	1.29 $\pm$ 0.25	<0.01	0.40 $\pm$ 0.05	1.50 $\pm$ 0.72	0.40 $\pm$ 0.02	<0.01	<0.01	60
γ -HCH	0.60 $\pm$ 0.02	1.15 $\pm$ 0.09	1.10 $\pm$ 0.3	0.75 $\pm$ 0.03	1.05 $\pm$ 0.04	0.60 $\pm$ 0.08	1.15 $\pm$ 0.09	1.10 $\pm$ 0.21	0.75 $\pm$ 0.03	1.05 $\pm$ 0.04	100
heptachlor	<0.02	0.60 $\pm$ 0.11	<0.02	2.40 $\pm$ 0.13	2.40 $\pm$ 0.06	0.45 $\pm$ 0.08	0.60 $\pm$ 0.02	0.55 $\pm$ 0.03	0.12 $\pm$ 0.01	2.40 $\pm$ 0.08	83
aldrin	<0.02	<0.02	<0.02	0.25 $\pm$ 0.08	1.20 $\pm$ 0.07	<0.02	<0.02	<0.02	<0.02	<0.02	20
δ -chlordane	0.25 $\pm$ 0.01	0.05 $\pm$ 0.03	0.05 $\pm$ 0.01	0.25 $\pm$ 0.03	0.05 $\pm$ 0.01	0.25 $\pm$ 0.03	0.50 $\pm$ 0.02	0.05 $\pm$ 0.01	0.25 $\pm$ 0.01	0.05 $\pm$ 0.02	100
α -endosulfan	0.15 $\pm$ 0.02	0.10 $\pm$ 0.02	<0.01	<0.01	<0.01	0.25 $\pm$ 0.02	1.00 $\pm$ 0.05	<0.01	<0.01	<0.01	40
β -endosulfan	1.05 $\pm$ 0.04	5.60 $\pm$ 0.12	2.05 $\pm$ 0.22	1.25 $\pm$ 0.05	1.25 $\pm$ 0.03	1.05 $\pm$ 0.09	5.60 $\pm$ 0.77	2.20 $\pm$ 0.08	7.25 $\pm$ 0.88	1.25 $\pm$ 0.06	100
dieldrin	0.90 $\pm$ 0.20	0.95 $\pm$ 0.04	0.50 $\pm$ 0.09	0.60 $\pm$ 0.01	0.60 $\pm$ 0.01	0.90 $\pm$ 0.07	0.95 $\pm$ 0.06	0.50 $\pm$ 0.03	0.70 $\pm$ 0.02	0.60 $\pm$ 0.03	100
endrin	0.75 $\pm$ 0.11	0.90 $\pm$ 0.07	0.95 $\pm$ 0.16	1.20 $\pm$ 0.09	1.20 $\pm$ 0.07	0.75 $\pm$ 0.04	0.90 $\pm$ 0.07	0.95 $\pm$ 0.08	1.20 $\pm$ 0.02	1.20 $\pm$ 0.09	100
p,p-DDT	0.10 $\pm$ 0.01	<0.01	<0.01	<0.01	1.79 $\pm$ 0.07	0.15 $\pm$ 0.02	0.10 $\pm$ 0.01	<0.01	<0.01	<0.01	40
p,p-DDE	<0.01	3.60 $\pm$ 0.27	1.50 $\pm$ 0.08	1.25 $\pm$ 0.06	4.95 $\pm$ 0.14	<0.01	3.60 $\pm$ 0.36	1.50 $\pm$ 0.07	4.75 $\pm$ 0.55	0.25 $\pm$ 0.06	80
p,p-DDD	2.00 $\pm$ 0.21	0.65 $\pm$ 0.07	0.30 $\pm$ 0.02	3.01 $\pm$ 0.41	0.25 $\pm$ 0.05	2.00 $\pm$ 0.80	0.65 $\pm$ 0.04	0.30 $\pm$ 0.03	0.25 $\pm$ 0.05	2.90 $\pm$ 0.10	100
ndosulfans sulfate	15.23 $\pm$ 1.04	4.50 $\pm$ 0.32	<0.01	<0.01	6.65 $\pm$ 0.32	<0.01	4.50 $\pm$ 0.46	0.15 $\pm$ 0.05	6.65 $\pm$ 0.55	<0.01	60

methoxychlor	0.65±0.05	2.05±0.55	5.95±0.11	0.48±0.03	4.90±0.22	0.65±0.07	2.05±0.09	5.96±1.01	4.90±0.91	4.25±0.11	100
ΣHCHs	0.75±0.04	2.50±0.2	1.55±0.32	2.04±0.28	1.55±0.06	1.00±0.13	3.37±0.87	1.55±0.24	0.75±0.03	1.05±0.04	100
Σ DDTs	2.10±0.21	4.25±0.34	1.80±0.10	4.26±0.47	6.99±0.25	2.15±0.82	4.35±0.41	1.80±0.10	5.00±0.60	3.15±0.16	100
PCB 28	<0.01	<0.01	<0.01	0.55±0.22	<0.01	0.91±0.31	5.90±1.05	3.53±0.90	5.25±0.74	<0.01	0
PCB 52	5.79±1.23	5.51±1.34	4.87±1.53	5.45±0.15	5.43±0.96	<0.01	4.85±1.20	4.26±1.12	5.24±1.92	5.74±1.81	90
PCB 101	0.78±0.61	1.14±0.55	1.06±0.09	1.37±0.04	0.70±0.08	1.10±0.22	0.39±0.07	0.16±0.02	0.33±0.08	<0.01	90
PCB 153	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0
PCB 138	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.95±0.10	<0.01	3.90±0.63	<0.01	20
PCB 180	<0.01	<0.01	<0.01	5.03±0.12	<0.01	2.07±0.43	7.08±1.23	7.55±1.33	<0.01	<0.01	40
Σ PCBs	6.57±1.84	6.65±1.89	5.93±1.62	12.40±0.53	6.13±1.04	4.08±0.96	19.17±3.65	15.50±3.37	14.72±3.37	5.74±1.81	100

249 % occ = percentage occurrence

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260 Table 3: Comparison of the present study to Darko et al (2008). Concentrations in ppb
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Compounds	Present study	Darko et al (2008)[8]	Rochel at al (2007)[10]
P,P ¹ -DDT	<0.01 – 0.25	0.012 – 4.41	-
p,p ¹ –DDD	<0.01 – 6.35	-	-
P,P ¹ -DDE	<0.01 – 4.95	0.016 – 8.342	-
DDTs	0.15 – 5.00	-	124.10
α-HCH	<0.01 – 1.15	-	-
β-HCH	<0.01 – 0.50	-	-
γ-HCH	<0.01 – 1.15	0.015 – 1.26	-
δ-HCH	<0.01 – 1.29	-	-
HCHs	<0.15 - 2.50	-	206.00
endrin	<0.02 - 1.20	-	-
dieldrin	<0.02 - 0.90	0.030 - 0.42	15.53
aldrin	<0.02 - 0.25	0.024 - 0.35	11.30
α-endosulfan	<0.01 – 1.00	-	-
β-endosulfan	<0.01 – 7.25	-	-
ndosulfans sulfate	<0.01 – 15.23	-	-
methoxychlor	<0.01 – 5.95	-	-
PCB 28	<0.01 – 5.90	-	-
PCB 52	0.75 – 5.79	-	-
PCB 101	<0.01 – 1.37	-	-
PCB 138	<0.01 – 3.90	-	-
PCB 153	<0.01	-	-
PCB 180	<0.01 – 7.55	-	-
PCBs	1.06 – 19.17	-	25.22

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263 - = not reported

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267 **3.2 Variation of DDTs in sediment**

268 Figure 2 shows the distribution of DDT and its metabolites in the sediments. In
269 Ghana DDT had been used extensively in the past for agriculture activities. However, the
270 use of DDT in Ghana has now been limited to malaria programs to fight the insect mosquito.
271 Indeed, its usage in agriculture had been banned by the Environmental Protection Agency of
272 Ghana [16]. Detected DDTs in the sediments were p, p¹ –DDT, p,p¹-DDE and p,p¹-DDD. p,
273 p¹ –DDT was only dominant at Pipie 2. In most of the sample locations it was not detected.
274 p,p¹-DDE on the other hand, was the predominant DDT in the sediments from Anyinatiase,
275 Abaase, Obo and Brodekwamo while p,p¹-DDD was the predominant DDT at Esaase,
276 Aborodwom, Nkawi, Adwafo. p,p¹-DDD was however, detected with 100 percentage
277 occurrence. The ratio DDT / (DDE+DDD) was less than one in the sampling communities
278 except at Pipie 2. The ratio of DDT/(DDE+DDD) can be used to assess or estimate the
279 extent of DDT decomposition or identify the recent input of DDT in the environment [17, 18].
280 If the ratio is less than one then there is no recent input of DDT. The low concentration of
281 p,p¹-DDT compared to the sum of its metabolites (DDE+DDD), is an indication that there
282 might not be fresh input of the DDT in the study area. This therefore, suggests that DDTs
283 concentrations in the study area might mainly be due to historical use and environmental
284 persistence of the compound.

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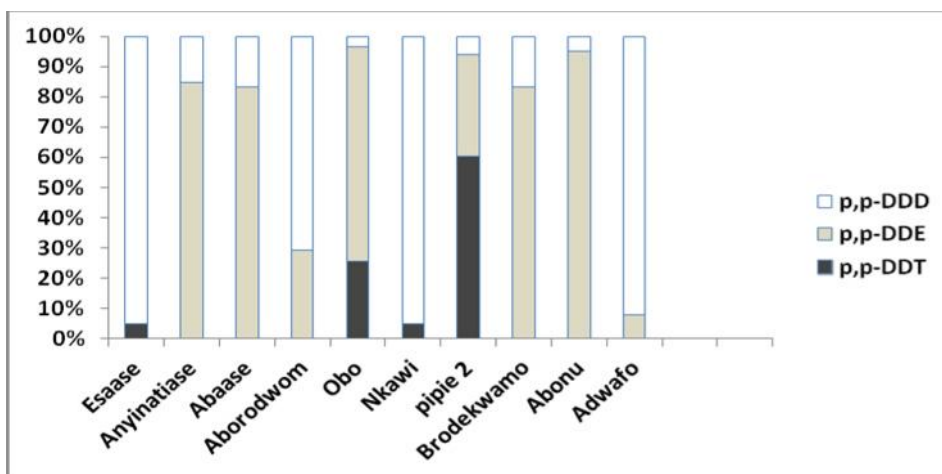


Figure 2: Percentage composition of DDTs in the sediments at various sampling points along Lake Bosumtwi

3.3 Variation of hexachlorocyclohexane (HCHs) in sediments

1,2,3,4,5,6-hexachlorocyclohexane was used since the beginning of the 20th century, first as technical mixture of the isomers (mainly as α , β , γ , δ -HCH isomers) and later in the form of γ -HCH (lindane) in protection of plants and woods against insect attack. It was also used to control parasites and pests in household. Research has shown that only the γ -isomer has insecticidal properties and was sold as insecticide under the trade name lindane [19, 20]. In Ghana lindane was historically used in the cocoa industry to control the insects that spread the swollen shoot disease. Because of its persistency, its usage in Ghana had been discontinued. Figure 3 shows the percentage distribution of HCHs in the sediments. It was only the γ -isomer that was detected with 100 percent occurrence. This was followed by δ -isomer with 66.66 percent occurrence. The α and β -isomeric forms were not very significant at the study. The prominence of the γ -isomer in the study area came as no surprise since the γ -HCH had previously been used in Ghana as a pesticide [21].

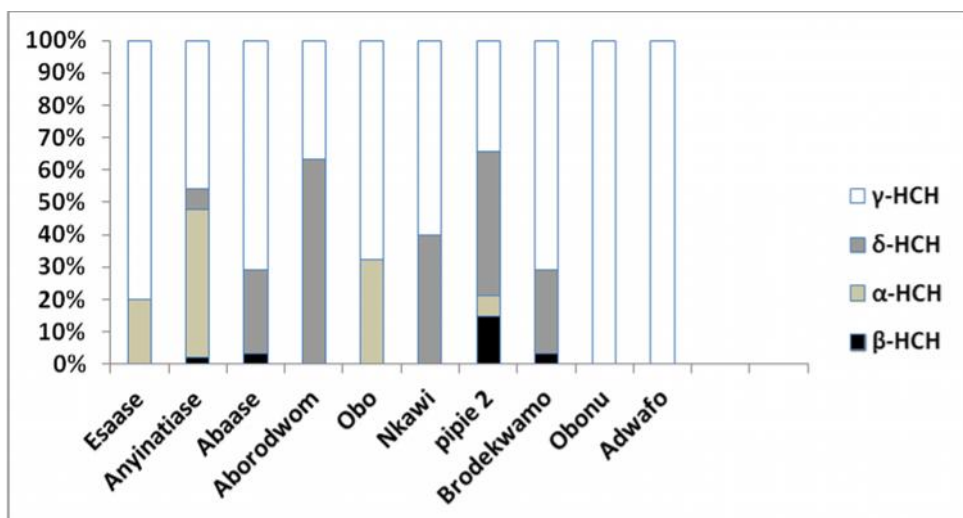


Figure 3: Percentage composition of HCHs in the sediments at various sampling locations along Lake Bosomtwi.

3.4 Variation of endosulfan in the sediment

Figure 4 presents the percentage composition of two isomeric forms of endosulfan and the metabolites (endosulfan sulfate) in the sediments. The results show that β is the predominant isomer in the sediment and accounted for more than 50 % of the total endosulfan load at most of the sampling points. Indeed, at Abaase, Aborodwom and Adwafo, the isomer accounted for 100 % of the total endosulfan load. The α -isomeric form was less prominent in the samples and accounted for between 5 – 10 % of the total endosulfan load at Nkawi and Pipie 2. Indeed, it was not detected in most of the sampling locations. This finding was interesting since technical endosulfan consists of 7: 3 mixtures for α and β stereo isomers [22]. This observation could be attributed to the stability or persistency of the β form in sediments. Endosulfan breaks down into endosulfan sulfate and endosulfan diol and both have structures similar to the parent compound. The two are therefore of toxicological concern. However, only the endosulfan sulfate was detected and accounting for more than 80 % of the total endosulfan load at Esaase and Obo. The metabolite was

also prominent at Anyinatiase, Pipie 2 and Obonu. The detection of endosulfan sulfate rather than endosulfan diol is an indication that metabolism of the parent occurred via oxidation rather than hydrolysis [23].

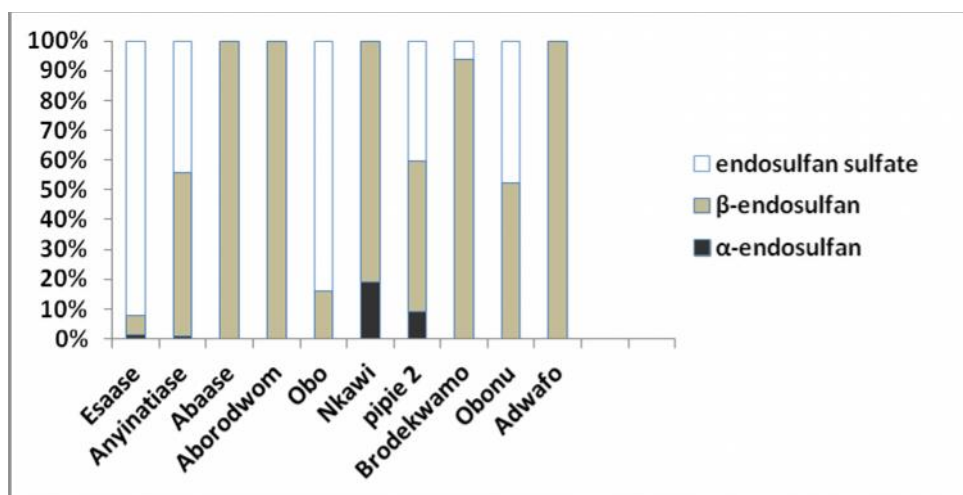


Figure 4: Percentage composition of the endosulfans at the various sampling locations along Lake Bosomtwi.

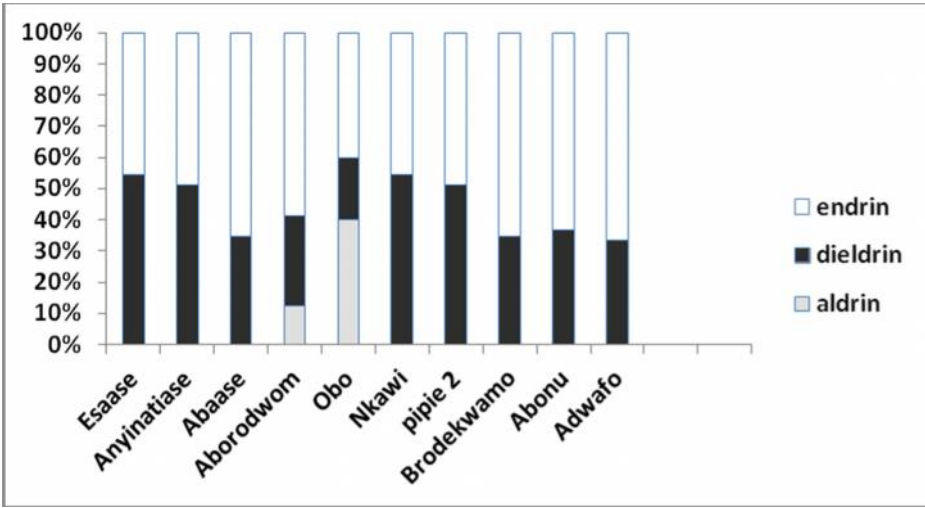
3.5 Variation of the Drin

Drin is a group name used for aldrin, dieldrin and endrin. They are among the banned insecticides by the Stockholm Convention. Aldrin and dieldrin are chemicals that were widely applied in agricultural throughout the world to control insects in soil. In the public health it was used for the control of mosquitoes and tsetseflies, the vectors that cause malaria and sleeping sickness respectively. Aldrin breaks down to dieldrin in living systems but dieldrin is known to resist bacterial and chemical breakdown in the environment [24]. Endrin had been used primarily as an insecticide on cotton as well as rodenticide and avicide. Figure 6 shows the profile of the drins in the sediments. From figure 5, dieldrin and endrin were the predominant Drin. The two accounted for 100 % of the total Drin load in eight of the sampling

354 locations. Aldrin was the least significant Drin in the sediment. Indeed it was detected only at
355 Aborodwom and Obo. The predominance of dieldrin over aldrin is not surprise at all since in
356 the environment aldrin is likely to break down to dieldrin [24]. In the environment endrin
357 ketone and endrin aldehyde are the degradation products of endrin through
358 photodecomposition and microbial degradation [21]. The fact that endrin ketone and endrin
359 aldehyde were not detected suggests that photodecomposition and microbial degradation of
360 endrin in the study area is not prominent

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365 Figure 5: Percentage compositions of the Drins at the various sampling locations along Lake
366 Bosomtwi.

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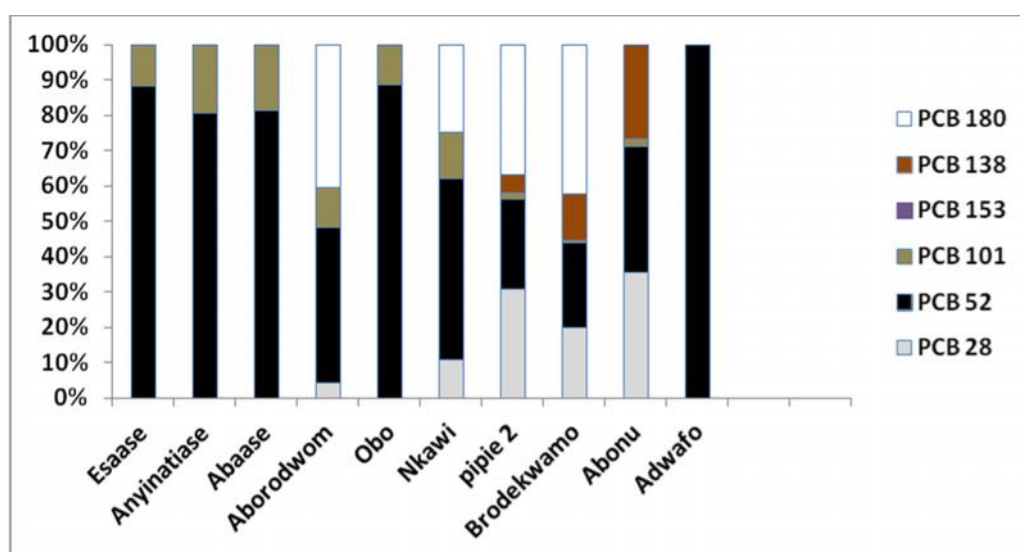
369 **3.6 Variation of the indicator PCBs congeners in the sediments**

370 Figure 6 presents the composition of detected indicator PCBs congeners. PCB 52 was the
371 most ubiquitous and predominant PCB congener in the study area, accounting for more than
372 50 % composition at five of the sampling locations. At Adwafo it was the only detected
373 indicator PCB congener. In general, the less chlorinated homologues (# 28, 52 and 101)

374 were more prominent than the most chlorinated homologues (# 138, 153 and 180). Indeed,
 375 PCB # 28, 52 and 101 were respectively detected with percentage occurrence of 50, 100
 376 and 91.6 %. The PCB congener 153 was not detected at any of the sampling locations while
 377 congener 138 was detected at three sampling locations. It was however, of interest to note
 378 that PCB 180 was quite prominent at some of the sampling locations and accounted for
 379 nearly 40 % of total PCBs load at Aborodwom, Pipie 2 and Brodekwo.

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384 Figure 6: Percentage composition of PCBs congeners at the various sampling locations
 385 along Lake Bosomtwi.

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388 3.7 Comparison of organochlorine residue levels to International standards

389 Table 4 compares mean organochlorine concentration of some of the detected
 390 organochlorines compounds in the present study to maximum residue limit (MRL) set by
 391 some International bodies [25]. Generally, the mean levels of the organochlorines in the
 392 Bosomtwi water were far below maximum residue limits set by European Union (EU), Italian

Government and Food and Agriculture Organization (FAO) (Table 4). The results, based on our one year monitoring, suggests that organochlorine compounds investigated in the present study may not pose health hazard in the waters from Lake Bosomtwi.

Table 4: Comparison of mean OCPs and PCBs concentrations (mg/kg) in the Lake waters to maximum residue limit (MRL) stipulated by some statutory agencies.

Compounds	This work	European Union MRL	Italian MRL	FAO, 1983
Σ chlordanes	<0.0002	0.0500	0.0500	
Σ DDT	0.0182	1.0000	1.0000	0.3000
dieldrin	0.0005	0.2000	0.2000	0.3000
α -HCH	<0.0002	0.2000	0.2000	
β -HCH	< 0.0002	0.1000	0.1000	0.3000
γ -HCH	0.0060	1.0000	1.0000	0.3000
endrin	<0.0002	0.0500	0.0500	0.3000
Σ PCB	0.0330	0.2000		

4. CONCLUSION

The results of this study indicate that some organochlorine compounds are present in the Bosomtwi Lake in Ghana. The detection of organochlorine compounds in waters and sediments of the Lake indicates either a historical use of these chemicals in the catchment of the lake or environmental transport from other places to the study area. However, in most of the sampling locations, particularly in the water samples concentrations of the compounds were below detection limit. In general there were more organochlorine compounds detected in the sediments than the water samples. Sediments may therefore serve as sink for

409 organochlorine compounds. The levels of organochlorine pesticides and PCBs in the Lake
410 water is far below the maximum residue limit of European Union, Italian Government and
411 Food and Agriculture Organization. In all PCB 52 was the most ubiquitous organochlorine
412 compound in the lake water with 100 percent frequency of occurrence while γ -HCH, endrin
413 and PCB 52 were the most ubiquitous compounds in the sediments, also with 100 percent
414 occurrence.

415

416 **ACKNOWLEDGEMENTS**

417 The authors are grateful to National Nuclear Research Institute of Ghana Atomic Energy
418 Commission for supporting the work and Mr. Paul Ofosu, Head of pesticide laboratory,
419 Ghana Standard Authority for his technical assistance.

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421 **COMPETING INTERESTS**

422 We the authors want to declare that there is no competing interest regarding publication of
423 the manuscript.

424

425 **AUTHORS' CONTRIBUTIONS**

426 This work is part of the corresponding author's Ph.D project which is being supervised by the
427 other three authors. Author SA did the sampling, laboratory works and prepared the
428 manuscript. JAM reviewed the scientific background. SO and STK explained the data and
429 dissected the results involved in the preparation of the manuscript. All authors read and
430 approved the final manuscript

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