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*Research Paper*

**Residues and Risk Assessment of Organochlorine Pesticides in Surface Sediment of Afram River of Ghana**

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**Abstract:** The Afram River is a major tributary of the Volta Lake in Ghana that has experienced intensive agricultural activities along its banks for over 50 years. Increased agricultural activities has raised concerns of contaminants entering the river ecosystem. Sediment being a major sink of chemical pollutants in aquatic systems is therefore the target of analysis in this research. Sediment samples were analysed for organochlorine pesticide (OCP) residues. Their concentration levels and possible risk they pose to aquatic biota were assessed. Sediment samples in acetonitrile medium were sonicated on ultrasonic bath, electronically shaken, cleaned by solid phase extraction and analysed by Gas Chromatograph equipped with electron capture detector. The mean concentration ranged from 1.55 µg/kg dry weight (dieldrin) to 42.69 µg/kg dry weight (γ-chlordane). Gamma Lindane recorded the highest incident rate of 97%. Based on sediment quality criteria of the United States National Oceanic and Atmospheric Administration (NOAA) and Canadian Sediment Quality Guidelines (CSQG), the concentrations of p,p-DDE and γ-lindane were assessed to have reached toxic levels that could present health and developmental hazards to aquatic fauna and therefore require priority remediation actions. The risk levels of p,p'-DDD, γ-chlordane, dieldrin, and endrin were also significant enough and constitute hazard.

**Keywords:** Sediment, Contamination, Organochlorines pesticides, Toxicity, Risk assessment, Volta Lake, Afram River.

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**Introduction**

Globally, there is widespread pollution of fresh water bodies since numerous anthropogenic activities, including agriculture occur around them. This is of much concern since fresh water bodies are the main sources of potable water for many communities. The persistence and mobility of pesticides in soils, coupled with their ability to dissolve in water, greatly contribute to their potential to contaminate water<sup>[1]</sup>. Pesticides may be in dissolved phase or associated with soil particles when they enter surface water column. The particle-associated pesticides in aquatic medium may subsequently be deposited to the bed sediment and remain in this domain for a very long time. Sediments therefore represent a principal long-term environmental

sink of pesticides for bioaccumulation and trophic transfer and from which food chains, the overlying water column as well as ground water could be contaminated<sup>[1-3]</sup>. The presence of contaminants in sediments could pose direct health and developmental hazards to benthic and demersal fauna, depending on their level of concentrations. Temitope et al, demonstrated that organic pollutants in the sediment of the Lagos Lagoon, Nigeria have embryotoxic and genotoxic effects on embryo of zebrafish<sup>[4]</sup>. For this reason, once chemical contamination level reaches a point at which it causes adverse effect to biota, sediment is considered polluted and hence merits remediation intervention. To determine whether sediment is contaminated or not, its quality or toxicity

is first determined and compared with internationally established sediment quality criteria or guidelines. Decisions are then made whether it presents risk or not.

Afram River is a major tributary of the Volta Lake that has experienced intense agricultural activities along its bank for well over 50 years. The agricultural activities in the distant past depended heavily on the input of organochlorine pesticides for increased yield. Of particular concern is the high dependence on banned organochlorine pesticides like lindane, aldrin, chlordane and heptachlor in the past. Even though the use of such organochlorines pesticides (OCPs) has been drastically reduced, if not eliminated, in recent times, their persistence and bioaccumulative natures have raised serious concerns about their residual levels in the environment. Of particular concern is the dearth of research into possible pesticide pollution of the aquatic environment. As part of a larger research project to assess pesticide pollution in the environmental compartments of the Afram arm of the Volta Lake, this particular work assesses concentration levels of organochlorine insecticides and their toxicity in surface sediment of Afram River.

## Materials and Methods

### Study area

The study area lies along the lower bank of the River Afram, a tributary of the Volta Lake and located within the coordinates: N 06° 34' 124" - 06° 43' 696" and W 000° 14' 089" - 000° 37' 810". The entire study area is under the same land use type of mainly fruits and vegetables cultivation with the input of the same agro-chemicals. The topography of the area is generally hilly with undulating landforms. The parent rocks are mainly the Birimian formation and Voltaian metamorphosed sediments. The area experiences mean monthly temperature of 26°C in the wet season to as high as 30°C in the dry season and a double maxima rainfall during the period of May to October, with just slight deviations, and a mean value between 150 mm to about 2000 mm. Sampling was done in areas of the river adjoining large scale commercial irrigation farms.

### Chemicals and Reagents

Methylene chloride, Acetonitrile, Ethyl acetate and Acetone were of purest grade (pesticide grade) and so were anhydrous sodium sulphate and sodium chloride. All these were acquired from BDH laboratory Supplies, England. Silica gell was purchased from Phenomenex (Torrence, CA, USA). Pesticides reference standards with high purity (Purity > 99%) were obtained from Dr. Ehrenstofer GmBH (Augsburg, Germany) for the following 16 organochlorine pesticides that were analysed:  $\alpha$ -lindane,  $\beta$ -lindane,  $\gamma$ -Lindane,  $\delta$ -lindane, aldrin, heptachlor,  $\gamma$ -chlordane,  $\alpha$ -endosulfan, *p,p'*DDE, dieldrin, endrin,  $\beta$ -endosulfan, *p,p'*-DDT, *p,p'*-DDD, endosulfan-sulfate and methoxychlor.

### Sampling of sediment

Grab samples of fine textured lake sediment were collected from the bottom of the river. As much as possible, sediment samples were taken at mid-stream points where the Afram River was not very broad; otherwise, samples were generally taken at an approximate distance of at least 30 metres from the bank. Samples were taken at four points along the Afram River where intensive irrigation farming is practiced. Composite samples were pooled from three subsamples and properly homogenized. The samples were wrapped in aluminium foils, placed in zip-locked plastic bags, stored on ice at approximately 4°C during transport and brought to the pesticide laboratory of the Ghana Standard Authority where they were stored in a deep freezer at -4°C, pending analyses.

### Extraction of pesticides from sediment samples

Sediment was wet extracted following the method of Muir & Sverko,<sup>5</sup> with necessary modifications. Briefly, sediment samples were removed from storage freezers and allowed to thaw. The percentage of water in each sample was determined by accurately weighing 10g, drying at 70°C and reweighing to a constant dry weight. A wet weight equivalent to 10g dry sample was calculated for each sample and extracted. Each sample was placed in a 100ml separating flasks and 10 mL acetonitrile added. The flasks were stoppered and sonicated for 5 minutes in a Decon sonicator model FS 400B. A further 10mL acetonitrile was added, placed on a horizontal mechanical shaker and set to shake continuously for 30 minutes at 300 motions per minute. The mixture in each flask was allowed to stand for 10 minutes and the organic phase was decanted and dried over 5g anhydrous magnesium sulphate through No. 1 Whatman filter paper. Ten millilitres aliquots of the filtrate were introduced into 50mL round-bottomed flasks and evaporated to 1mL concentrate using Bauchi rotary vacuum evaporator. Each sample was extracted in duplicate. For the third extraction, sediment samples were spiked with standard pesticide mix solutions and taken through the entire extraction process in order to determine recovery efficiency.

### Sample clean-up

Clean-up of the extracted samples from section 2.4 was done by column chromatography. Ten millilitres polypropylene cartridge was packed with 2g of activated silica gel (previously conditioned by heating at 130°C for 2 hours) packed between two layers, each of 1g sodium sulphate and the column was conditioned with 10mL of acetonitrile and not allowed to dry. The 1mL extract concentrates were then loaded onto the conditioned cartridges and eluted with 10mL portion of acetonitrile. The eluate was collected into round-bottom flasks and evaporated to dryness using rotary vacuum evaporator and redissolved in 2mL ethyl acetate (HPLC grade) for Gas Chromatograph analysis

### Instrumental analysis

Organochlorines pesticides in the final pesticide extracts were analyzed by Gas Chromatograph-Varian CP-3800 (Varian Association Inc. USA) equipped with combiPal autosampler and Ni electron capture detector (ECD). The GC conditions used for the analysis were capillary column coated with VF-5 (30 m + 10 m guard column x 0.25 mm i.d, 0.25 μ m film thickness). The injector and detector temperature were set at 270°C and 300°C respectively. The oven temperature programmed as follows: 70°C held for 2 minute, ramp at 25°C min<sup>-1</sup> to 180°C, held for 1 min and finally ramp at 5°C min<sup>-1</sup> to 300°C. Nitrogen was used as carrier gas at a flow rate of 1.0 mL min<sup>-1</sup> and detector make-up gas of 29 mL min<sup>-1</sup>. The injection volume of the GC was 1.0 μ L. the total run time for a sample was 31.4 min.

### Analytical quality control

Recoveries were calculated for three replicates of sediment samples spiked with 5 ml of 0.05 μg/L standard mixture solutions of organochlorine pesticides. The percentage recovery ranged between 93 -104% which was considered a good range. Reagents were also extracted in the same manner as samples and found to be devoid of any interfering agents and for each batch of 20 samples, a pair of spiked samples were processed. Precision of the analysis was verified by 5 repeated injections of the spiked concentration (0.05 μg/L). Deviation from the expected values ranged between 1.2 and 8.9%. Limit of quantification (LOQ) of the method was assessed based on lowest analyte concentration that could consistently and reliably yield 70% or more recovery from spiked samples and also gave signal: noise ratio<sup>6</sup> of 3. This lowest concentration was run 10 times and the standard deviation (SD) of the signals calculated. Three times the SD gave the limit of detection (LOD) while 10 times the SD gave the limit of quantification. The LOQ for the pesticides was 0.01 μg/kg while limit of detection was 0.003 μg/kg. Recalibration curves were run with each sample batch to ensure that correlation coefficient was not below 0.99. All glassware was washed with hot water and detergents and copiously rinse with distilled water. After drying, the glass wares were further rinsed with acetone.

### Data analysis

Preliminary analysis of the data showed that there were no significant differences among all the parameters from the various sampling points (P > 0.05) after performing the test of normality. The entire data was therefore pooled together and analysed to examine trends in the entire study area. Means were calculated based on number of samples in which residues were quantified. Pie and bar charts were used to illustrate

where appropriate and frequencies of occurrence of individual pesticides were recorded as incidence rates.

### Risk Assessment

In determining toxicity, sediment quality values, which provide scientific benchmarks, or reference points, for evaluating the potential for observing adverse biological effects in aquatic systems were employed in this study. The level of risk posed by a pesticide in the sediments was characterized by risk quotient of the pesticide, which is a ratio of the pesticide's concentration in sediment to its quality value<sup>[7]</sup>.

$$RQ = \frac{MEC}{SQV} \dots \dots \dots (1)$$

RQ= Risk quotient for pesticide in sediment  
MEC= measured environmental concentration (in total sediment) for pesticide  
SQV= sediment quality value for pesticide

Approaches to sediment quality assessment typically employ two concentration threshold values; a lower limit of sediment quality value, below which effects rarely occur and an upper value, above which harmful effects on sediment-dwelling organisms are likely to occur<sup>[2]</sup>. According to Fung *et al.*,<sup>[8]</sup> values of the two thresholds can be used to calculate risk quotients under the best-case (RQb) and the worst-case (RQw) scenarios as follows:

$$RQ_b = \frac{\text{Lowest measured concentration of a chemical in sediment}}{\text{Upper threshold of sediment quality value}} \dots \dots \dots (2)$$

$$RQ_w = \frac{\text{Highest measured concentration of a chemical in sediment}}{\text{Lower threshold of sediment quality value}} \dots \dots \dots (3)$$

The determination of RQb and RQw present a simple way of characterizing the risk associated with a pesticide in the sediment. In principles, if the RQb and RQw calculated values are greater than 1, then the pesticides in question could pose risk and therefore require remedial attention. Conversely if the value of RQb and RQw are less than 1, the chemical is probably of little concern and thus could be accorded a lower management or remediation priority attention. In situations where both risk quotients do not present the same interpretations, (e.g. RQb < 1 and RQw >1) then a more refined risk assessment must be undertaken to ascertain the risk due to specific chemicals<sup>[7]</sup>.

### Results and Discussion

#### General trend

The concentration of contaminants in the sediment follows the trend: DDTs > γ-chlordane > HCHs > Endosulfans > Drins (aldrin, dieldrin and endrin) (Figure 1). The top four single pollutants with concentrations above 10 μg/kg occurred in the order: γ-

chlordane > *p,p'*-DDD > *p,p'*-DDE >  $\gamma$ -HCH (Table 1) and the ranking order of incidence rate of the top five pollutants also follows:  $\gamma$ -HCH > *p,p'*-DDD >  $\beta$ -HCH > endosulfan sulfate >  $\gamma$ -chlordane/ $\delta$ -HCH. Gamma-chlordane constituted the single major contaminant in the sediment, constituting 25% of the entire OCPs. Chlordane, especially the gamma isomer is known to be stable, persistent and highly adsorbent to sediment

particles<sup>[9]</sup> and unlike most OCPs, it has limited bioaccumulation in the adipose tissues of aquatic organisms<sup>[10]</sup>. The high concentration of gamma-chlordane may therefore be explained by its tendency and ability to persist and adsorb onto sediment particles.

**Table 1: Concentration and incidence rate of pesticide residues in sediment**

Pesticides	Mean $\pm$ SD ( $\mu\text{g}/\text{kg}$ )	Range ( $\mu\text{g}/\text{kg}$ )	Incidence rate (%)
<i>Organochlorines</i>			
$\beta$ -HCH	2.16 $\pm$ 0.9	0.50-3.50	53.0
$\gamma$ -HCH	14.67 $\pm$ 8.4	1.52-38.95	97.0
$\delta$ -HCH	9.39 $\pm$ 12.9	0.50-55.00	47.0
Heptachlor	4.10	4.10	3.0
Aldrin	2.88 $\pm$ 4.6	1.40-17.60	37.5
$\gamma$ -Chlordane	42.69 $\pm$ 27.3	1.60-95.00	47.0
$\alpha$ -endosulfan	2.18 $\pm$ 0.5	1.70-3.50	37.5
<i>p,p'</i> -DDE	31.00 $\pm$ 9.7	14.80-49.80	37.5
Dieldrin	1.55 $\pm$ 0.4	1.20-2.50	37.5
Endrin	4.55 $\pm$ 0.1	4.40-4.80	25.0
Beta endosulfan	5.20	4.00-6.40	6.0
<i>p,p'</i> -DDT	4.60 $\pm$ 2.0	0.50-8.80	37.5
<i>p,p'</i> -DDD	35.76 $\pm$ 29.5	3.69-91.55	72.0
Endosulfan sulfate	2.12 $\pm$ 0.7	1.00-3.30	50.0
Methoxychlor	6.10 $\pm$ 1.8	5.00-9.60	19.0

**Table 2: Estimated risk quotients of organochlorine pesticides concentrations in sediments based on Canadian Sediment Quality Guideline (CSQG) and National Oceanic and Atmospheric Administration (NOAA) guidelines**

Pesticide	OCPc	NOAA ( $\mu\text{g}/\text{kg}$ )		CSQG ( $\mu\text{g}/\text{kg}$ )		1>RQb>1	0.1<RQw<1	1<RQw<10	RQw>10
		ERL	ERM	TEL	PEL				
<i>p,p</i> -DDD	3.69-91.55	2.0	20	3.54	8.51	○●			○●
<i>p,p</i> -DDE	14.8-48.8	2.0	27	1.42	6.8	●○			○●
<i>p,p</i> -DDT	0.50-8.80	1.0	7	-	-	●		●	
$\gamma$ -chlordane	1.60-95.0	0.5	6	4.5	8.9	○●			○●
Dieldrin	1.20-2.50	0.02	8	2.85	6.67	○●	○		●
Endrin	4.40-4.80	0.02	8	2.67	62.4	○●		○	●
$\gamma$ -Lindane	1.52-49.0	0.32	1	0.94	1.38	○●			○●

Risk quotients were calculated based on two sediment quality criteria (○ = CSQG; ● = NOAA)

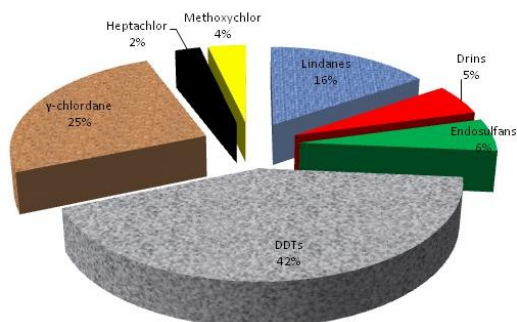
OCPc = Organochlorine pesticides concentration range

ERL = Effect range-low; ERM = Effect range-medium {of the US National Oceanic and Atmospheric Administration (NOAA) guidelines}.

TEL = Threshold effect level; PEL = Probable effect level {based on Canadian Sediment Quality (CSQG) Guideline}

**DDT and its metabolites (*p,p'*-DDE and *p,p'*-DDD)**

DDT and its metabolites constituted the major fraction (42%) of the organochlorine pesticide residues in the sediment of the Afram River (Figure 1).

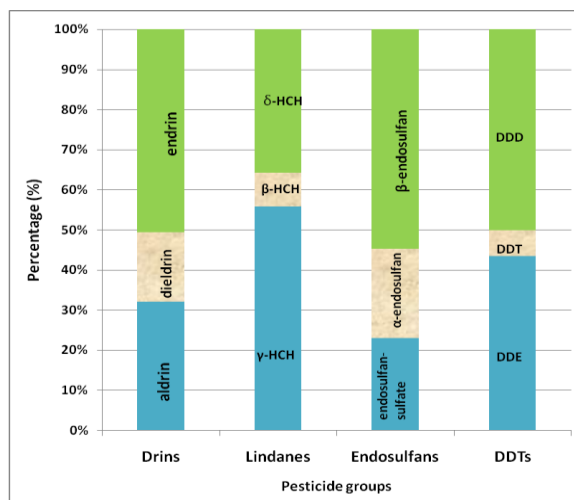


**Figure 1: Percentage composition of organochlorine pesticide in sediment of the Afram River**

The mean concentrations of DDTs occurred in increasing order of: *p,p'*-DDT < *p,p'*-DDE < *p,p'*-DDD with respective values of 4.60  $\mu\text{g}/\text{kg}$ , 31.00  $\mu\text{g}/\text{kg}$  and 35.76  $\mu\text{g}/\text{kg}$ . The *p,p'*-DDD fraction of total DDTs constitutes about 50% (Figure 2). Due to its environmental persistence and health hazards, DDT and formulations containing its metabolites have been banned from agricultural use under the Stockholm convention<sup>[11]</sup> to which Ghana is a signatory. Higher concentrations of metabolite compounds *p,p'*-DDD and *p,p'*-DDE relative to the parent compound *p,p'*-DDT, as recorded in the sediment during this study are therefore not surprising. The preponderance of *p,p'*-DDD and *p,p'*-DDE does not only suggest historical use of DDT but also indicates the high rate of DDT degradation that is typical of tropical waters with hot climatic conditions<sup>[12]</sup>. DDE is normally the more stable metabolite and its level is expected to be higher. In this study however, the *p,p'*-DDD concentration is observed to be higher (Table 1). This observation may be attributed to the fact that the main degradation pathway is from DDT to DDD by reductive dechlorination process<sup>[13, 14]</sup>.

The current trend of higher *p,p'*-DDD and *p,p'*-DDE relative to *p,p'*-DDT was also observed by Ntow<sup>[15]</sup> in sediment from the Volta Lake, Darko, Akoto and Oppong<sup>[16]</sup> in sediment from Lake Bosomtwi, as well as by Pazou *et al.*,<sup>[17]</sup> from sediment of Nokoue and Cotonou Lagoons in Benin and Doong *et al.*,<sup>[18]</sup> from sediment of Wu-Shi River estuary in Taiwan. Whereas the concentration levels recorded in this study were lower than those reported by Ntow<sup>[15]</sup>, they were higher than those reported by Darko *et al.*,<sup>[16]</sup> The present investigation to some extent, therefore,

confirms the restricted use of DDT for agricultural purposes in Ghana.



**Figure 2: Percentage composition of pesticides occurring in lindanes, drins, endosulfans and DDT groups**

**Concentration of lindanes in the bed sediment**

Alpha-lindane was the only lindane not detected in any of the sediment samples. The mean concentrations of  $\gamma$ -HCH,  $\delta$ -HCH and  $\beta$ -HCH were 14.67  $\mu\text{g}/\text{kg}$ , 9.39  $\mu\text{g}/\text{kg}$  and 2.16  $\mu\text{g}/\text{kg}$  respectively. Gamma-lindane residue concentration did not only contribute to more than 55% of total lindane concentration (Figure 2), but it was also the most ubiquitous of all the OCPs encountered, with incident rate of 97% (Table 1). Even though the use of lindanes in Ghana has been banned, they still persist in the environment due to their extensive use in the past for crop production and animal husbandry<sup>[19]</sup>. Gamma HCH in particular was marketed as Gammalin 20 until 2007 when its use was discontinued<sup>[20]</sup>. In the case of the Afram River sediment, the high  $\gamma$ -HCH:  $\beta$ -HCH (6.8) suggests that either lindane ( $\gamma$ -HCH) is still in current use or the degradation of historically used lindane to the more stable  $\beta$ -HCH in the sediment is very slow.

The trend of higher  $\gamma$ -HCH and  $\delta$ -HCH concentrations relative to that of  $\beta$ -HCH follows that recorded in July, 2002 by Fernandez-Bringas *et al.*,<sup>[21]</sup> in Mexico ( $\gamma$ -HCH-0.43 ng/g,  $\delta$ -HCH-0.37 ng/g and  $\beta$ -HCH- 0.16 ng/g) and locally by Kuranchie-Mensah *et al.*,<sup>[20]</sup> at Weija ( $\gamma$ -HCH -0.555  $\mu\text{g}/\text{kg}$  and  $\delta$ -HCH - 0.140  $\mu\text{g}/\text{kg}$ ) and Nsawam ( $\gamma$ -HCH -0.608  $\mu\text{g}/\text{kg}$  and  $\delta$ -HCH - 0.095  $\mu\text{g}/\text{kg}$ ). The range of concentration of lindanes in the sediment of Afram River appears high (Table 1) when compared with work done by Doong *et al.*,<sup>[18]</sup> in Taiwan (0.57  $\mu\text{g}/\text{kg}$  - 14.1  $\mu\text{g}/\text{kg}$ ) and Sun *et al.*,<sup>[22]</sup> in Huaihe River, China (1.95  $\mu\text{g}/\text{kg}$  - 11.05  $\mu\text{g}/\text{kg}$ ).

### Endosulfan and its metabolite endosulfan sulfate in River Sediment

The parent compounds;  $\alpha$ -endosulfan and  $\beta$ -endosulfan recorded higher mean concentrations relative to that of the metabolite, endosulfan sulfate while the metabolite had higher incidence rate (50%) (Table 1). The presence of endosulfan in the sediment may therefore be due to both current and historical uses. Field survey established the use of Thiodan, an endosulfan-based insecticide, by farmers in controlling bollworms in fruits and vegetables. The range of concentration of endosulfan sulfate in the sediment of Afram River (1.00 – 3.30  $\mu\text{g}/\text{kg}$ ) compared to that of Lake Victoria (0.82  $\mu\text{g}/\text{kg}$  – 6.62  $\mu\text{g}/\text{kg}$ ), as reported by Wasswa *et al.*,<sup>[23]</sup> was lower. The mean concentration of each of the compound was however observed to be 6 to 30 folds higher than what was reported by Ntow<sup>[15]</sup> in sediments ( $\alpha$ -endosulfan – 2.18  $\mu\text{g}/\text{kg}$ ,  $\beta$ -endosulfan – 5.2  $\mu\text{g}/\text{kg}$  and endosulfan sulfate – 2.12  $\mu\text{g}/\text{kg}$ ) from some other parts of the Volta Lake. Current higher values, compared to what was reported by Ntow<sup>[18]</sup>, signify intensification of agricultural activities along the banks of the Volta Lake in general, and Afram River in particular. Levels of endosulfan in this study however are in good agreement with recorded values from Densu River sediment by Kuranchie-Mensah *et al.*,<sup>[20]</sup>

### Concentration of the drins (aldrin, dieldrin, endrin) in sediment

Drins is a group name used for aldrin, dieldrin and endrin. They are among the insecticides banned by the Stockholm Convention. Aldrin and dieldrin were used in the public health for the control of mosquitoes and tsetse fly vectors that cause malaria and sleeping sickness respectively. Endrin on the other hand has been used primarily as an insecticide<sup>[24]</sup> and therefore potential for runoff into aquatic systems. The profile of the drins, as shown in Figure 2 reveals that endrin alone accounts for about 50% of the drins. Aldrin transforms rapidly into dieldrin in the environment<sup>[1]</sup> and there is the possibility of dieldrin transforming into its isomer, endrin. Wang *et al.*,<sup>[25]</sup> had endrin:dieldrin ratios above unity in their determinations. In this study also, the ratios of endrin: aldrin (1.6) and endrin: dieldrin (2.9) clearly suggest the presence of endrin in the sediment was due to recent inputs. Similarly, the low dieldrin: aldrin ratio (0.5) indicates the possibility of fresh aldrin usage. The use of the drins in Ghana, just like the lindanes and the DDTs, has been banned. The indication of recent inputs of aldrin and endrin can only be explained by covert peddling of these chemicals from house to house in the study area, as confirmed by some of the farmers. The strong adsorption of Aldrin to sediment particles for a long time<sup>[26]</sup> coupled with its slow photolytic and biological degradation (into dieldrin) in sediment<sup>[27]</sup> may also

accounts for its appreciable residual concentration and low levels of dieldrin in the sediment.

### Pesticide toxicity and risk assessment

The sediment quality values used in the calculation of risk quotients were the Canadian Sediment Quality Guidelines (CSQG) and the United States National Oceanic and Atmospheric Administration guidelines (NOAA)<sup>[2]</sup>. Only contaminants for which sediment quality values have been established were assessed. Assessment of potential environmental risk associated with the OCPs in this study is summarized in Table 2. The sediment quality values used in calculating the risk quotients were the Threshold Effect Level (TEL) and Probable Effect Level (PEL) of the Canadian Sediment Quality Guidelines (CSQG), as well as the Effect Range-Low (ERL) and Effect Range-Median (ERM) of the US National Oceanic and Atmospheric Administration (NOAA) guidelines. TEL and ERL represent lower threshold values while PEL and ERM represent upper limits in their respective guidelines. Pesticides with clearly defined risk status are *p,p'*-DDE,  $\gamma$ -HCH and dieldrin. For  $\gamma$ -HCH, risk quotients based on both CSQG and NOAA are greater than one (1) under best and worst case scenarios (RQb and RQw respectively). For *p,p'*-DDE, the risk quotient (RQ) is greater than one under best and worst case scenarios based on CSQG only (Table 2). Concentrations of these contaminants have therefore reached toxicity levels whereby they can impact on health of sediment and benthic organisms in particular, and affect the integrity of the Afram River ecosystem as a whole. These pesticides in the sediment may therefore require priority attention for some control measures. Similar studies carried out by Fung *et al.*,<sup>[8]</sup> on sediment of Pearl River in China listed DDT (and its metabolites), dieldrin and endrin as serious contaminants with RQs under best case scenarios greater than 10. Nemr *et al.*,<sup>[28]</sup> also listed DDT, chlordane and endrin with RQs above 10 in sediment from Egyptian Mediterranean coast.

In the case of dieldrin in this study, the RQ based on CSQG is less than unity under both best and worst case scenarios. Hence this pesticide is of little concern. The risk quotient for *p,p'*-DDT, *p,p'*-DDD and endrin were all above 1 under worst case scenario and at the same time below 1 under best case scenarios. Hence the actual risks posed by these contaminants (*p,p'*-DDT, *p,p'*-DDD and endrin) even though may need further investigation, cannot be overlooked.

### Conclusion

The study revealed the presence of a wide range of organochlorine pesticide residues in sediment of the Afram River. Although the presence of most of them was due to historical inputs and environmental persistence, others like endosulfan,  $\gamma$ -HCH, aldrin and

endrin suggest current input. Risk assessment study suggests that concentrations of  $\gamma$ -HCH and  $p,p'$ -DDE have reached toxic levels and pose potential risk to the local aquatic system. In view of this, there is the need to closely monitor the use of pesticides in agricultural fields along Afram arm and indeed along the entire Volta Lake to protect the aquatic system from further contamination. This will safeguard the food chain in the aquatic system and protect the integrity of important ecosystem services and livelihood opportunities they provide.

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#### Conflict of interest

The authors declare that they have no conflict of interest.

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