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Research Article

Human Risk Assessment of Organochlorine Pesticide Residues in Vegetables from Kumasi, Ghana

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The use of organochlorine pesticides has been banned worldwide due to their toxicities. However, some farmers use them illegally because of their potency. The aim of this study was to assess the level of organochlorine pesticide (OCP) residues and the potential health risk associated with vegetables, soil, and groundwater obtained from farms in Ayigya, Nsenie, Gyenyase, and Kentinkrono in Kumasi, Ghana. A total of 15 samples were analyzed using a gas chromatograph equipped with an electron capture detector. The highest mean concentration of $184.10 \pm 12.11\,\mu$g/kg was recorded for methoxychlor in cabbage from Ayigya. Beta-hexachlorocyclohexane (beta-HCH) recorded the lowest mean concentration of $0.20 \pm 0.00\,\mu$g/kg in cabbage from Ayigya. The combined risk index showed significant health risk to children than adults. The soil samples mainly contained methoxychlor followed by dichlorodiphenyltrichloroethane (DDT), aldrin, and other OCPs. Concentrations of total HCHs, total DDTs, and total OCPs in the soil samples ranged from <0.01 to 49.00, <0.01 to 165.81, and <0.01 to 174.91 μg/kg, respectively. Among all HCH and DDT isomers, only β-HCH and p,p'-DDT were detected in some of the water samples. Carcinogenic risk values for β-HCH, aldrin, and p,p' DDT in the groundwater were found to be $>10^{-6}$, posing a potentially serious cancer risk to consumers. Moreover, the hazard quotients (HQs) of aldrin exceeded the threshold value of one, indicating that daily exposure is a potential concern.

1. Introduction

There are increasing reports of hunger in various parts of the globe due to increasing world population [1, 2]. This has led to an increase in efforts towards the achievement of Goal 2 of the Sustainable Development Goals (SDGs)—zero hunger [3]. To accomplish this all-important goal, various strategies for pest control [4], irrigation, and resistant crop varieties [5] are being developed. Pesticide use, either in field or post-harvest, has largely contributed to improved crop yield, with its attendant economic benefits [6].

Ghana's agriculture sector employs more than half of her population in both formal and informal basis. It is the single largest contributor to the country's gross domestic product (GDP) and export earnings [7]. Over two-thirds of Ghana's population is rural based and heavily dependent on agriculture for their livelihoods [8]. It is estimated that more than 80% of Ghanaian farmers use pesticides in their operations [9–11]. Irresponsible use of pesticides may lead to the prevalence of pesticide residues in the environment and agriculture [12]. It is confirmed that pesticide residues exceeding a threshold pose a possible risk for consumers [12–15]. The toxic effects include acute neurological toxicity, disturbances in the immune and reproductive system, and several other diseases. Of the major classes of pesticides on the market, organochlorines have received a lot of attention from the scientific community due to their low cost, versatility against various pests, persistency, bioaccumulative nature, and potential toxicity to humans and to wildlife [11–17]. Because of their ability to bioaccumulate and often harm unintended species, organochlorine pesticides (OCPs) have been outlawed in Ghana, with a switch to the less persistent organophosphorus and synthetic pyrethroids being favored [13, 18, 19].

Vegetables constitute a major part of the human diet by contributing to the dietary requirements of nutrients [20–22]. Lettuce, cabbage, and onions are some of the most consumed vegetables in Ghana. Many farmers in both rural and urban communities have taken up vegetable production on a commercial basis. Many consumers purchase their vegetables directly from the market, whereas few obtain it from the farms [23]. To improve yield, farmers are using a large amount of OCPs during the entire period of vegetable cultivation, even at the fruiting stage. Residues of pesticides accumulate in the vegetables, the soil, and in nearby water bodies (from runoffs). The problem of residue accumulation needs more attention in vegetables because they are consumed either raw or without much processing [24, 25]. Pesticide residues in vegetables constitute a possible risk to consumers, and a number of reports have documented this [26–31].

The soil serves as a reservoir for persistent organic pollutants and plays an important role in their global distribution [32]. Soil not only has a large retention capacity but also reemits OCPs into the environment as a secondary source [33]. A significant proportion of hexachlorocyclohexanes (HCHs) and dichlorodiphenyltrichloroethanes (DDTs), ranging from 20 to 70% of its degradation products, may remain in the soil after having been applied [34]. DDT and the rest of persistent OCPs have been found in soil samples and distributed throughout the environment [34]. The transfer of OCPs from the soil surface layers to lower depths may impact their volatilization rates from surface soil and thus impose potential risks for shallow groundwater [35, 36].

Despite global attempts to eliminate OCPs, there is still evidence of their presence in various matrices from both abiotic and biotic components since a considerable amount of pesticides applied ultimately end up in water bodies. In this study, the levels of organochlorine pesticide residues in three different vegetables, lettuce, onion, and cabbage, were determined from farms in five different communities in Kumasi, Ghana. Fifteen different organochlorine pesticides were analyzed in this study. These were γ-HCH, β-HCH, δ-HCH, heptachlor, aldrin, γ-chlordane, α-endosulfan, β-endosulfan, endosulfan sulphate, p,p'-DDE, p,p'-DDD, p,p'-DDT, dieldrin, endrin, and methoxychlor. The levels of OCP residues on soils and water used in vegetable were also assessed. The potential human health risks associated with consumption of contaminated vegetables were estimated.

2. Materials and Methods

2.1. Reagents. All chemicals used were of analytical grade. The mixed standard of OCPs (methoxychlor, α-endosulfan, β-endosulfan, α-, β-, γ-, and δ-hexachlorocyclohexane (HCH), heptachlor, dieldrin, aldrin, endrin, endosulfan sulphate, p,p'-DDE, p,p'-DDD, p,p'-DDT, and gamma-chlordane) was obtained from Supelco (PA, USA). Standard stock solutions of 10 mg/L were prepared in methanol. Analytical grade acetone, sodium sulphate, ethyl acetate, and sodium hydrogen carbonate were obtained from the CDH group, New Delhi, India. *n*-Hexane was of residue grade (Romil, Cambridge-UK).

2.2. Study Area. Kumasi is the capital of the Ashanti Region in Ghana. It is the second largest city and one of the fastest growing metropolitan areas in Ghana, with an estimated population of over two million and an annual growth rate of 5.47% [37]. It covers a total area of 57 sq·km, and the topography of the region varies from gently undulating, hilly to mountainous clear. The region has two main seasons, the rainy and dry seasons. The rainy season is characterized by heavy rains from March to July and light rain between September and November, with an annual rainfall of about 1300 mm. Relative humidity varies between 1270 and 1410 mm, the mean daily sunshine duration between 2 and 7 hours, and the daily minimum and maximum temperature of 21.20 and 35.50°C [38]. The unique position and the availability of infrastructure in conjunction with the main markets have made Kumasi a center of trade in the Ashanti Region. The Kumasi Central Market is one of the largest markets in Africa. Another significant market in the metropolis is the Asafo Market, which is the second largest in the region.

2.3. Samples

2.3.1. Vegetables. Three different vegetables (cabbage, lettuce, and onion) were obtained from five different farms (Kentinkrono, Ayigya, Nsenie, Gyenyase, and Anglican Hostel) in Kumasi in September 2014. The sampling stations are shown in Figure 1. The vegetable samples were taken from different beds on each farm and bulked together as composites. About 1 kg of each type of vegetable from each farm was used for analysis.

2.3.2. Water. Groundwater from sites close to each of the sampling stations was also collected. Samples were collected free of air bubbles in clean 1 L amber glass bottles and stored in the dark at 4°C. One milliliter of 2.5% NaN_3 was added to each bottle and stoppered.

2.3.3. Soil. Topsoil samples from each sampling site were collected at 0–30 cm depth using a spiral auger and composited. The samples were wrapped in clean aluminium foils. They were then placed in clean zip lock bags. The soil samples, directly after collection, were kept in a refrigerator prior to laboratory analysis.

2.4. Sample Extraction

2.4.1. Vegetables. To about 10 g of homogenized vegetable was added 50 mL of 1 : 1 acetone/ethyl acetate. The homogenate was sonicated in an ultrasonic bath (Branson 220, Branson Ultrasonic Cleaner, USA) for 1 hour at 40°C. Extracts were filtered with Whatman no. 42 filter paper. The extracts were then dried over anhydrous sodium sulphate and concentrated to about 5 mL in vacuo (BÜCHI Rotavapor R-200 rotary evaporator). Extracts were then subjected to cleanup procedures, as indicated in the following section.

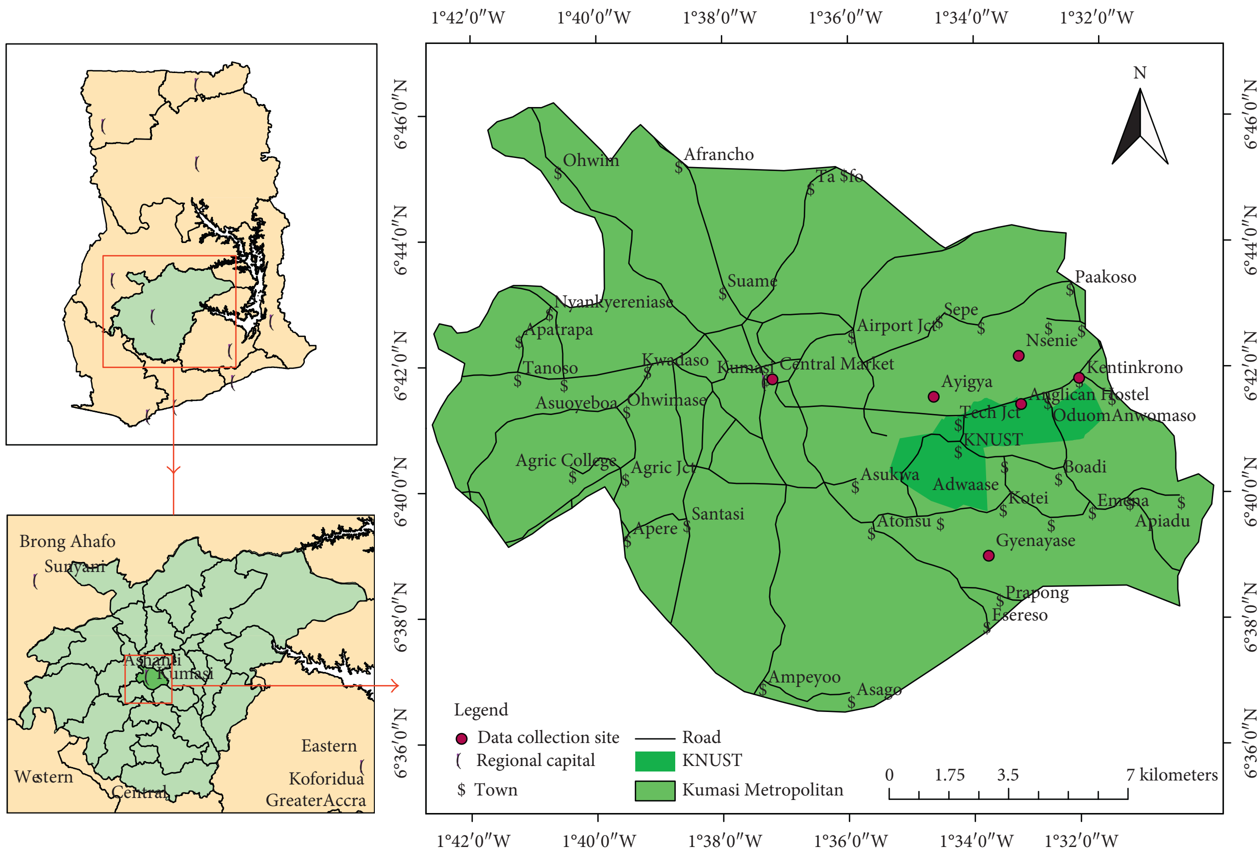

Figure 1: A map showing the study areas in Kumasi, Ashanti Region, Ghana.

2.4.2. Soil. To 2.5 g of soil sample was added 50 mL 3 : 1 hexane/acetone. The resulting mixture was sonicated in an ultrasonic bath (Branson 220, Branson Ultrasonic Cleaner, USA) for 1 hour at 40°C [39]. The extracts were filtered (Whatman no. 42), dried over anhydrous sodium sulphate, and concentrated to about 5 mL in vacuo (BÜCHI Rotavapor R-200 rotary evaporator) followed by cleanup, as indicated in the following section.

2.4.3. Water. A 20 mL portion of filtered (Whatman no. 42, 12.5 cm filter paper) water sample was shaken with 20 mL of hexane in a separating funnel. The hexane extract was then separated from the aqueous layer. Extraction was repeated thrice, and the combined hexane extracts were dried over anhydrous sodium sulphate. The extract was then concentrated in vacuo (BÜCHI Rotavapor R-200 rotary evaporator) to about 5 mL and then subjected to cleanup procedures, as indicated in the following section.

2.5. Cleanup. A combined florisil-silica solid phase extraction (SPE) column was prepared by packing 1.5 g and 0.5 g preactivated florisil and silica adsorbent material, respectively, with 1.0 g anhydrous sodium sulphate packed on top of the adsorbents in a glass column. The packed columns were then conditioned with 10 mL of hexane. The extract was applied to the preconditioned column, and the flow-through was collected into a 50 mL conical flask. The column was eluted first with 15 mL of hexane followed by 5 mL of 2 : 1 hexane/diethyl ether. The eluate was concentrated almost to dryness in vacuo (BÜCHI Rotavapor R-200 rotary evaporator), and eluate was resuspended in 1.5 mL ethyl acetate. The extract was finally transferred into 2 mL glass vial for analysis [10].

2.6. Gas Chromatographic Analysis. A Varian CP-3800 gas chromatograph equipped with an electron capture detector (ECD) and VF-5ms capillary column ($30\,m \times 0.25\,mm \times 0.25\,\mu m$) was used for pesticide residue analysis. Nitrogen was used as the carrier gas at a flow rate of 1 mL/min. The injector and detector temperatures were set to 270°C and 300°C, respectively. The GC oven was initially set at 70°C (with a 2 min hold), then increased to 180°C at a rate of 25°C/min (1 min hold), and then to 300°C at 5°C/min and held for 15 minutes.

One microliter of 0.5 mg/L standard solution of organochlorine pesticide mix was injected into the GC. Peak identification was conducted by comparing the retention time of the authentic standards and those obtained from the extracts and quantified by the external standard method.

2.7. Quality Assurance. The efficiency of the method of analysis was determined by recovery of an external standard. Five vegetable samples, one from each farm, were spiked with 0.5 mg/L of external standard each and extracted and under the same conditions as the rest of the samples. Each spiked sample was run in triplicates and mean determined.

Table 1: Recoveries and method detection limits (MDLs) for the analysis of the 15 OCPs.

Pesticide	MDL (μg/kg)	% recovery
γ-HCH	0.39	104.00
β-HCH	0.34	89.60
Heptachlor	0.39	105.07
δ-HCH	0.28	74.27
Aldrin	0.42	112.00
γ-Chlordane	0.41	109.73
α-Endosulfan	0.29	77.73
p,p'-DDE	0.30	80.93
Dieldrin	0.29	76.93
Endrin	0.39	103.73
p,p'-DDD	0.33	88.27
β-Endosulfan	0.38	99.86
p,p'-DDT	0.38	100.27
Endosulfan sulphate	0.35	92.93

Mean recovery of OCPs ranged from 74.27 to 112.00% (Table 1). Method detection limits (Table 1) were computed by determining the lowest concentrations of the residues in each of the matrices that could be reproducibly measured at the operating conditions of the GC using a signal-to-noise ratio of 3 : 1. All analyses were carried out in triplicates, and the mean concentrations were calculated.

2.8. Health Risk Assessment: Vegetables. The United States Environmental Protection Agency's guidelines [40] were used to estimate potential health risk associated with consumption of organochlorine pesticides. Body weights of 10 kg for children and 60 kg for adult were used. The vegetable consumption rate was estimated to be 0.137 μg/kg/day in Ghana [40]. Consequently, for each type of organochlorine pesticide exposure, the estimated daily intake (μg/kg) was obtained using the following equation:

$$\mathrm{EDI} = \frac{(C \times \mathrm{CR})}{\mathrm{BW}}, \tag{1}$$

where EDI is the estimated daily intake, C is the concentration of the pesticide residue (μg/kg), CR is the consumption rate (kg/day), and BW is the average body weight (kg) of Ghanaian children and adults.

Hazard indices (HIs) for humans were computed as ratios between estimated daily intake (EDI) and the acceptable daily intake (ADI) which are considered to be harmless levels of exposure over the lifetime. When HI is >1, it indicates that lifetime consumption of vegetables containing the measured level of OCP residues could pose health risks [41]. The HI was calculated from the following equation:

$$\mathrm{HI} = \frac{\mathrm{EDI}}{\mathrm{ADI}}. \tag{2}$$

The combined risk of multiple OCP pollutants was estimated using the hazard index combination (HIC), as given in the following equation:

$$\mathrm{HI} = \frac{B_1}{L_1} + \frac{B_2}{L_2} + \ldots + \frac{B_n}{L_n} = \sum_{i=1}^{n} \frac{B_i}{L}, \tag{3}$$

where B_1, B_2, B_n, and B_i represents the levels of exposure of each discrete pesticide (i) in a mixture of n pesticides. L_1, L_2, L_n, and L_i are the maximum acceptable levels (ADIs) for every pesticide [42]. If the indices are >1, the mixture has exceeded the maximum permissible level and may cause a potential risk to consumers.

The carcinogenic risk associated with consumption of these vegetables was also estimated. Test concentration of carcinogenic effects was obtained using the US EPA oral slope factor. The risk assessment was carried out on the basis of the concentration of OCPs residues in vegetables. Hazard ratios (HRs) was calculated by dividing the estimated daily intake (EDI) by the benchmark concentrations (BCs) for cancer [43]:

$$\begin{aligned} \mathrm{HR} &= \frac{\mathrm{EDI}}{\mathrm{BC}}, \\ \mathrm{BC} &= \frac{\text{risk} \times \text{body weight}}{\text{vegetable consumption rate} \times \text{slope factor}}. \end{aligned} \tag{4}$$

The benchmark concentration is derived by setting the cancer risk to one in one million due to lifetime exposure [42].

3. Results and Discussions

3.1. OCPs in Vegetables. OCPs were detected in cabbage samples from all farms except those from Nsenie. In Ayigya, 6 OCPs were detected in varying concentrations from the samples. Gyenyase, Kentinkrono, and Anglican Hostel tested positive for the presence of 2, 3, and 4 OCPs, respectively. OCPs detected include β-HCH, γ-HCH, δ-HCH, endosulfan sulphate, p,p'-DDT, and methoxychlor. All others were below the detection limit. Methoxychlor was detected in samples from Ayigya (184.10 ± 12.11) and Anglican Hostel (9.02 ± 0.65). The level of methoxychlor in Ayigya is about 20 folds higher than the set EU MRL (10 μg/kg). δ-HCH and p,p'-DDT were present in samples from all farms except Nsenie. Gyenyase had the highest level of δ-HCH with a concentration of 12.41 ±0.14 μg/kg which was above the EU MRL [43]. The levels of p,p'-DDT detected in all samples were, however, below the set EU MRL. Kentinkrono cabbage samples had the highest level of p,p'-DDT.

OCPs were detected in lettuce samples from all five locations. p,p'-DDT was detected in samples from all locations. Levels of methoxychlor and aldrin (detected in samples from 4 locations) were all above the set EU MRL, with Ayigya samples recording the highest methoxychlor concentration of 165.21 ± 12.65 μg/kg. Kentinkrono had the highest aldrin concentration. The only OCP detected in samples from Anglican Hostel was p,p'-DDT. The concentration was however below the EU MRL. δ-HCH, γ-chlordane, p,p'-DDE, p,p'-DDD, β-endosulfan, and endosulfan sulphate were not detected in any of the lettuce samples.

δ-HCH and dieldrin were the only OCPs detected in onion samples from Ayigya and Anglican Hostel, respectively, and the levels were all lower than the EU MRL. γ-HCH was only detected in onion samples from Anglican Hostel, with the levels above the EU MRL. Once again, methoxychlor (detected in Gyenyase, Kentinkrono, and Anglican Hostel samples) levels were well above the permissible limits, with values ranging from 40–160 μg/kg. p,p'-

Table 2: Concentrations, EDI, and health risk estimation for OCP residues detected in vegetables from Ayigya.

Sample	Pesticide	Mean ± SD (μg/kg)	EU/WHO MRL (μg/kg)	ADI	EDI		HI	HR
Cabbage	β-HCH	0.20 ± 0.01	10	3	4.57×10^{-3}	Adult	1.52×10^{-4}	No
					3.43×10^{-3}	Child	9.13×10^{-4}	No
	γ-HCH	1.40 ± 0.41	10	3	3.20×10^{-3}	Adult	1.07×10^{-3}	No
					1.92×10^{-2}	Child	6.39×10^{-3}	No
	δ-HCH	1.50 ± 1.81	10	3	3.43×10^{-3}	Adult	1.14×10^{-3}	No
					2.06×10^{-2}	Child	6.85×10^{-3}	No
	p,p'-DDT	5.67 ± 0.44	50	20	1.29×10^{-2}	Adult	6.47×10^{-4}	No
					7.77×10^{-2}	Child	3.88×10^{-3}	No
	Endosulfan sulfate	$28.47 \pm 2.68^{*}$	10	6	6.50×10^{-2}	Adult	1.08×10^{-2}	No
					3.90×10^{-1}	Child	6.50×10^{-2}	No
	Methoxychlor	$184.10 \pm 12.11^{*}$	10	5	4.20×10^{-1}	Adult	8.41×10^{-2}	No
					2.52×10^{1}	Child	5.04×10^{-1}	No
Lettuce	γ-HCH	9.54 ± 0.02	10	3	2.18×10^{-2}	Adult	7.26×10^{-3}	No
					1.31×10^{-1}	Child	4.36×10^{-2}	No
	Heptachlor	2.29 ± 0.14	10	0.1	5.23×10^{-3}	Adult	5.23×10^{-2}	No
					3.14×10^{-2}	Child	3.14×10^{-1}	No
	Aldrin	$22.66 \pm 0.15^{*}$	10	0.2	5.17×10^{-2}	Adult	2.59×10^{-1}	No
					3.10×10^{-1}	Child	1.55×10^{0}	Yes
	α-Endosulfan	0.60 ± 0.28	10	6	1.37×10^{-3}	Adult	2.28×10^{-4}	No
					8.22×10^{-3}	Child	1.37×10^{-3}	No
	Dieldrin	1.49 ± 0.14	10	0.2	3.40×10^{-3}	Adult	1.70×10^{-2}	No
					2.04×10^{-2}	Child	1.07×10^{-1}	No
	Endrin	1.69 ± 0.42	10	0.2	3.86×10^{-3}	Adult	1.93×10^{-2}	No
					2.32×10^{-2}	Child	1.16×10^{-1}	No
	p,p'-DDT	9.34 ± 0.22	50	20	2.13×10^{-2}	Adult	1.07×10^{-3}	No
					1.28×10^{-1}	Child	6.40×10^{-3}	No
	Methoxychlor	$165.21 \pm 12.65^{*}$	10	5	3.77×10^{-1}	Adult	7.54×10^{-2}	No
					2.26×10^{1}	Child	4.53×10^{-1}	No
Onion	δ-HCH	0.78 ± 0.23	10	3	1.78×10^{-3}	Adult	5.94×10^{-4}	No
					1.07×10^{-2}	Child	3.56×10^{-3}	No
Soil	β-HCH	3.73 ± 1.83	—	—	—	—	—	—
	Aldrin	1.20 ± 0.57	—	—	—	—	—	—
	p,p'-DDT	50.25 ± 2.24	—	—	—	—	—	—
	Methoxychlor	15.40 ± 3.95	—	—	—	—	—	—
Groundwater	Aldrin	$1.00 \pm 0.18^{*}$	0.03	—	—	—	—	—
	p,p'-DDT	$2.80 \pm 1.93^{*}$	2.00	—	—	—	—	—

Note: mean ± standard deviation of 3 determinations; *above the EU/WHO MRL; for groundwater, WHO MRLs were used; for vegetables, EU MRLs were used; —, not applicable.

DDT levels were, however, lower than EU MRLs in detected samples from Gyenyase and Anglican Hostel. The levels of aldrin in Anglican Hostel samples were twice above the EU MRL. Aldrin was also present in samples from Gyenyase and Nsenie. Endrin was found in samples from Anglican Hostel (1.21 ± 0.10) and Gyenyase (6.73 ± 0.05).

Two of the analytes, p,p'-DDD and p,p'-DDE, are metabolites of the toxic organochloride p,p'-DDT. The isomers of endosulfan (α and β) and HCH are limited to specific uses. They are to be employed only for the control of capsids on cocoa, stem borers in maize, and pests on coffee [44]. The results from this study showed the presence of DDT residues on onions, cabbages, and lettuces from various farms. DDT was detected on all lettuce from all farms sampled in this work, an indication of its widespread use. Though the levels never exceeded the EU MRL, the presence of residues of DDT in these vegetables shows that farmers are still illegally applying this pesticide on their farms. Under anaerobic conditions, DDT degrades slowly to DDD and to DDE under aerobic conditions [45–48]. DDE and DDD were not detected in any vegetable sample analyzed in this study.

When present, methoxychlor was usually detected at levels above the permissible limit. In samples from Ayigya, the concentrations were as high as 20 times above the permissible limit. The high levels detected is a sign of recent use. Initially designed as DDT substitute, its acute toxicity led to its ban. It is known to be a neurotoxin and a carcinogen [49, 50]. Its presence in vegetables is therefore worrying. Earlier studies by other research teams corroborate these findings in that DDT was also detected in various farms produces. DDT was detected in vegetables from markets in Kumasi with concentrations between 4 and 50 μg/kg [27]. Other pesticides detected included methoxychlor, γ-HCH, and aldrin. The authors also indicated that the presence of high concentrations on these OCP residues is a sign of recent use [9, 10]. Together, this current study and others previously done, show that farmers are still using these harmful pesticides.

Table 3: Concentrations, EDI, and health risk estimation for OCP residues detected in vegetables from Gyenyase.

Sample	Pesticide	Mean ± SD (μg/kg)	EU/WHO MRL (μg/kg)	ADI	EDI		HI	HR
Cabbage	δ-HCH	12.41 ± 0.14*	10	3	2.83×10^{-2}	Adult	9.45×10^{-3}	No
					1.70×10^{-1}	Child	5.67×10^{-2}	No
	p,p'-DDT	0.34 ± 0.02	50	20	7.76×10^{-4}	Adult	3.88×10^{-5}	No
					4.66×10^{-3}	Child	2.33×10^{-4}	No
Lettuce	β-HCH	2.10 ± 1.84	10	3	4.80×10^{-3}	Adult	3.95×10^{-3}	No
					2.80×10^{-2}	Child	2.37×10^{-2}	No
	γ-HCH	5.19 ± 0.01	10	3	1.19×10^{-2}	Adult	1.60×10^{-3}	No
					7.11×10^{-2}	Child	9.59×10^{-3}	No
	Heptachlor	2.30 ± 0.14	10	0.1	5.25×10^{-3}	Adult	5.25×10^{-2}	No
					3.15×10^{-2}	Child	3.15×10^{-1}	No
	Aldrin	15.58 ± 0.28*	10	0.2	3.56×10^{-2}	Adult	1.78×10^{-1}	No
					2.13×10^{-1}	Child	1.07×10^{0}	Yes
	α-Endosulfan	1.30 ± 0.42	10	6	2.97×10^{-3}	Adult	4.95×10^{-4}	No
					1.78×10^{-2}	Child	2.97×10^{-3}	No
	Endrin	3.60 ± 0.01	10	0.2	8.22×10^{-3}	Adult	4.11×10^{-2}	No
					4.93×10^{-2}	Child	2.47×10^{-1}	No
	p,p'-DDT	5.09 ± 3.53	50	20	1.16×10^{-2}	Adult	5.81×10^{-4}	No
					6.97×10^{-2}	Child	3.49×10^{-3}	No
	Methoxychlor	25.57 ± 0.34*	10	5	5.84×10^{-2}	Adult	1.17×10^{-2}	No
					3.50×10^{-1}	Child	7.01×10^{-2}	No
Onion	β-HCH	11.15 ± 0.27*	10	3	2.55×10^{-2}	Adult	8.49×10^{-3}	No
					1.53×10^{-1}	Child	5.09×10^{-2}	No
	Aldrin	7.88 ± 0.27	10	0.2	1.80×10^{-2}	Adult	9.00×10^{-2}	No
					1.08×10^{-1}	Child	5.40×10^{-1}	No
	α-Endosulfan	1.54 ± 0.01	10	6	3.52×10^{-3}	Adult	5.86×10^{-4}	No
					2.11×10^{-2}	Child	3.52×10^{-3}	No
	Endrin	6.73 ± 0.05	10	0.2	1.54×10^{-2}	Adult	7.68×10^{-2}	No
					9.22×10^{-2}	Child	4.61×10^{-1}	No
	p,p'-DDT	4.42 ± 0.54	50	20	1.10×10^{-2}	Adult	5.05×10^{-4}	No
					6.06×10^{-2}	Child	3.03×10^{-3}	No
	Methoxychlor	160.96 ± 12.24*	10	5	3.68×10^{-1}	Adult	7.35×10^{-2}	No
					2.21×10^{1}	Child	4.41×10^{-1}	No
Soil	β-HCH	12.00 ± 1.13	—	—	—	—	—	—
	Heptachlor	1.07 ± 0.39	—	—	—	—	—	—
	Aldrin	3.78 ± 0.51	—	—	—	—	—	—
	p,p'-DDT	27.20 ± 2.90	—	—	—	—	—	—
	Methoxychlor	8.68 ± 4.22	—	—	—	—	—	—
Groundwater	β-HCH	1.63 ± 0.00	2.00	—	—	—	—	—
	Aldrin	0.35 ± 0.07*	0.03		—	—	—	—
	p,p'-DDT	3.63 ± 0.02*	2.00	—	—	—	—	—

Note: mean ± standard deviation of 3 determinations; *above the EU/WHO MRL; for groundwater, WHO MRLs were used; for vegetables, EU MRLs were used; —, not applicable.

Due to the high cost of pesticide residue analysis, consistent monitoring of food for residues is almost non-existent in Ghana. Despite efforts to educate farmers and the general public on the dangers associated with the use of pesticides, there is little incentive for farmers to change their usual practices as the authorities lack the necessary resources to pursue them [44]. It is therefore important that households are educated on the need to demand and adhere to thorough washing and cooking procedures for vegetables before consumption. This will go a long way in reducing risks associated with vegetable consumption.

3.2. OCPs in Soil and Water. The levels of OCPs in soils and water from farms in the five sampling sites were also investigated in this study (Tables 2–6). Of the OCPs under investigation, seven (β-HCH, γ-HCH, heptachlor, aldrin, p,p'-DDD, p,p'-DDT, and methoxychlor) were present in soil samples from the five locations. The levels ranged from 0.09 to 58.30 μg/kg. Methoxychlor, p,p'-DDT, and β-HCH were detected in soil samples from all locations. The highest concentrations of methoxychlor and p,p'-DDT were found in soil from Anglican Hostel. Kentinkrono recorded the highest level of β-HCH. Interestingly, p,p'-DDD, which was absent in all vegetable samples, was present in soil from Nsenie. Aldrin was not detected in soil from Anglican Hostel but was present in soil from all other locations.

Aldrin, p,p'-DDT, methoxychlor, and β-HCH were the OCPs detected in water samples obtained from sites close to farms in the sampling locations. p,p'-DDT, present in all water samples, except Nsenie, was at concentrations greater than the WHO permissible limit of 2 μg/L. Methoxychlor was present

Table 4: Concentration, EDI, and health risk estimation for OCP residues detected in vegetables from Nsenie.

Sample	Pesticide	Mean ± SD (μg/kg)	EU/WHO MRL (μg/kg)	ADI	EDI		HI	HR
Lettuce	β-HCH	$12.00 \pm 1.70^*$	10	3	2.74×10^{-2}	Adult	9.13×10^{-3}	No
					1.64×10^{-1}	Child	5.48×10^{-2}	No
	Heptachlor	0.20 ± 0.01	10	0.1	4.57×10^{-4}	Adult	4.57×10^{-3}	No
					2.74×10^{-3}	Child	2.74×10^{-2}	No
	Aldrin	$21.50 \pm 0.42^*$	10	0.2	4.91×10^{-2}	Adult	2.45×10^{-1}	No
					2.95×10^{-1}	Child	1.47×10^{0}	Yes
	α-Endosulfan	4.10 ± 0.14	10	6	9.36×10^{-3}	Adult	1.56×10^{-3}	No
					5.62×10^{-2}	Child	9.36×10^{-3}	No
	Endrin	6.10 ± 0.42	10	0.2	1.39×10^{-2}	Adult	6.96×10^{-2}	No
					8.36×10^{-2}	Child	4.18×10^{-1}	No
	p,p'-DDT	11.50 ± 4.38	50	20	2.63×10^{-2}	Adult	1.31×10^{-3}	No
					1.58×10^{-1}	Child	7.88×10^{-3}	No
	Methoxychlor	$38.10 \pm 6.38^*$	10	5	8.70×10^{-2}	Adult	1.74×10^{-2}	No
					5.22×10^{-1}	Child	1.04×10^{-1}	No
Onion	β-HCH	$48.35 \pm 5.09^*$	10	3	1.10×10^{-1}	Adult	3.68×10^{-2}	No
					6.62×10^{-1}	Child	2.21×10^{-1}	No
	Heptachlor	0.90 ± 0.14	10	0.1	2.06×10^{-3}	Adult	2.06×10^{-2}	No
					1.23×10^{-2}	Child	1.23×10^{-1}	No
	Aldrin	5.49 ± 0.14	10	0.2	1.25×10^{-2}	Adult	6.27×10^{-2}	No
					7.52×10^{-2}	Child	3.76×10^{-1}	No
	Endosulfan sulfate	2.80 ± 0.28	10	6	6.39×10^{-3}	Adult	1.07×10^{-3}	No
					3.84×10^{-2}	Child	6.39×10^{-3}	No
Soil	β-HCH	0.53 ± 0.02	—	—	—	—	—	—
	Aldrin	0.09 ± 0.03	—	—	—	—	—	—
	p,p'-DDD	6.27 ± 1.70	—	—	—	—	—	—
	p,p'-DDT	4.01 ± 0.31	—	—	—	—	—	—
	Methoxychlor	2.61 ± 0.01	—	—	—	—	—	—
Groundwater	Aldrin	$3.57 \pm 0.09^*$	0.03	—	—	—	—	—
	Methoxychlor	8.87 ± 0.34	20.00	—	—	—	—	—

Note: mean ± standard deviation of 3 determinations; *above the EU/WHO MRL; for groundwater, WHO MRLs were used; for vegetables, EU MRLs were used; all OCPs were below detection limits in cabbage samples; —, not applicable.

in samples from 2 locations, with the levels lower than the WHO permissible limit. The levels of aldrin in Nsenie, Ayigya, and Gyenyase water samples were far greater than the permissible limit. Kentinkrono, Gyenyase, and Anglican Hostel samples recorded β-HCH levels lower than WHO limits.

The soil serves as a sink for pesticides. Although the levels in most soil samples were below the instruments detection limit, methoxychlor, p,p'-DDT, and β-HCH were present in soil samples from all five locations. Once again, the levels in Ayigya samples were unusually high. Interestingly, p,p'-DDD, the aerobic metabolite of p,p'-DDT, was detected in soil samples from Nsenie. Most farmers use water in rivers and streams around their farms for irrigation purposes. Water bodies get contaminated by runoffs from nearby farms. The levels of DDT detected in water from all farms, except Nsenie, were above the permissible limits. Aldrin in water from Nsenie was also above the WHO permissible limit. Because people use these water sources for other domestic purposes, the potential for a health hazard is great. In addition, the presence of these pesticides in the water bodies could alter the biodiversity of the aquatic ecosystem with unintended economic consequences arising from low fish catches amongst others [51].

3.3. Health Risk Assessments. Table 7 presents data on the combined health risks posed by consumption of the vegetables to adults and children. In general, consumption of these vegetables posed a greater risk to children than to adults. Consumption of lettuce from 4 out of the 5 locations could likely pose some health risks to children. Consumption of lettuce from the Anglican Hostel was less likely to pose any health risks to children. The hazard indices for the consumption of onions from Gyenyase and Anglican Hostel were greater than 1, whereas those from the other samplings sites were well below 1. For cabbage consumption, the greatest health risk to children was posed by samples from Ayigya. Both Ayigya and Gyenyase had at least two vegetables posing significant health risks to child consumers. Consumption of lettuce, cabbage, and onions from all five locations poses no significant health risks to adults.

The combined health risks estimated for adults for the consumption of cabbage, lettuce, or onion were all below 1. These results are similar to those obtained by Akoto et al. [9] for the consumption of okra, tomatoes, and eggplants from Kumasi. For children, the story is rather different. Hazard indices greater than 1 were obtained for the consumption of cabbage, lettuce, or onion from at least one of the sampling locations. It is therefore important that steps are taken to reduce the levels of pesticide residues on these vegetables. Thorough washing of vegetables and cooking could help eliminate some of these residues.

Table 5: Concentration, EDI, and health risk estimation for OCP residues detected in vegetables from Kentinkrono.

Sample	Pesticide	Mean ± SD (μg/kg)	EU/WHO MRL (μg/kg)	ADI	EDI		HI	HR
Cabbage	β-HCH	35.20 ± 0.35*	10	3	8.04×10^{-2}	Adult	2.68×10^{-2}	No
					4.82×10^{-1}	Child	1.61×10^{-1}	No
	δ-HCH	9.53 ± 0.28	10	3	2.18×10^{-2}	Adult	7.25×10^{-3}	No
					1.31×10^{-1}	Child	4.35×10^{-2}	No
	p,p'-DDT	31.73 ± 0.07	50	20	7.25×10^{-2}	Adult	3.62×10^{-3}	No
					4.35×10^{-1}	Child	2.17×10^{-2}	No
Lettuce	γ-HCH	7.16 ± 0.14	10	3	1.63×10^{-2}	Adult	5.45×10^{-3}	No
					9.81×10^{-2}	Child	3.27×10^{-2}	No
	Heptachlor	1.08 ± 0.14	10	0.1	2.47×10^{-3}	Adult	2.47×10^{-2}	No
					1.48×10^{-2}	Child	1.48×10^{-1}	No
	Aldrin	23.92 ± 0.28*	10	0.2	5.46×10^{-2}	Adult	2.73×10^{-1}	No
					3.28×10^{-1}	Child	1.64×10^{0}	Yes
	Dieldrin	4.22 ± 1.25	10	0.2	9.64×10^{-3}	Adult	4.82×10^{-2}	No
					5.78×10^{-2}	Child	2.89×10^{-1}	No
	Endrin	1.47 ± 0.14	10	0.2	3.36×10^{-3}	Adult	1.68×10^{-2}	No
					2.01×10^{-2}	Child	1.01×10^{-1}	No
	p,p'-DDT	4.51 ± 0.83	50	20	1.03×10^{-2}	Adult	5.15×10^{-4}	No
					6.18×10^{-2}	Child	3.09×10^{-3}	No
	Methoxychlor	57.75 ± 25.93*	10	5	1.32×10^{-1}	Adult	2.64×10^{-2}	No
					7.91×10^{-1}	Child	1.58×10^{-1}	No
Onion	β-HCH	4.07 ± 2.67	10	3	9.29×10^{-3}	Adult	3.10×10^{-3}	No
					5.58×10^{-2}	Child	1.86×10^{-1}	No
	Endosulfan sulfate	2.18 ± 3.20	10	6	4.98×10^{-3}	Adult	8.30×10^{-4}	No
					2.99×10^{-2}	Child	4.98×10^{-3}	No
	Methoxychlor	88.29 ± 9.02*	10	5	2.02×10^{-1}	Adult	4.03×10^{-2}	No
					1.21×10^{1}	Child	2.42×10^{-1}	No
Soil	β-HCH	16.30 ± 1.69	—	—	—	—	—	—
	Aldrin	5.46 ± 2.02	—	—	—	—	—	—
	p,p'-DDT	34.59 ± 2.33	—	—	—	—	—	—
	Methoxychlor	3.41 ± 0.81	—	—	—	—	—	—
Groundwater	β-HCH	1.03 ± 0.01	2.00	—	—	—	—	—
	p,p'-DDT	2.07 ± 0.03*	2.00	—	—	—	—	—
	Methoxychlor	1.53 ± 0.00	20.00	—	—	—	—	—

Note: mean ± standard deviation of 3 determinations; *above the EU/WHO MRL; for groundwater, WHO MRLs were used; for vegetables, EU MRLs were used; —, not applicable.

The carcinogenic risk values for vegetables from all the farms were <1 and therefore raise no immediate concern to consumers.

Even though the hazard indices recorded in this study were low for adult consumers, it does not imply full proof safety. Pesticide residues could accumulate over a period of time, and this could have adverse chronic effects on adult consumers [9].

4. Conclusion

The results from this study underline the presence of OCPs in cabbage, lettuce, and onions from farms in Nsenie, Kentinkrono, Gyenyase, Anglican Hostel, and Ayigya. Residues were also detected in soils and water samples from these locations. The results indicate that the residues are probably from recent applications of pesticides. Consumption of these vegetables by children could present both carcinogenic and noncarcinogenic health risks. Adults are less likely to have any health risk from consuming these vegetables. However, care should be taken since residues could accumulate and pose chronic health hazards. Enforcing the laws on the import and use of toxic pesticides will go a long way to reduce risks associated with the consumption of contaminated vegetables. Washing and/or cooking vegetables before consumption should also be encouraged as it has the potential of reducing levels of pesticide residues in food.

Data Availability

Supplementary data will be available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Table 6: Concentration, EDI, and health risk estimation for OCP residues detected in vegetables from Anglican Hostel.

Sample	Pesticide	Mean ± SD (μg/kg)	EU/WHO MRL (μg/kg)	ADI	EDI		HI	HR
Cabbage	β-HCH	14.76 ± 3.57*	10	3	3.37×10^{-2}	Adult	1.12×10^{-2}	No
					2.02×10^{-1}	Child	6.74×10^{-2}	No
	δ-HCH	7.91 ± 0.02	10	3	1.81×10^{-2}	Adult	6.02×10^{-3}	No
					1.08×10^{-1}	Child	3.61×10^{-2}	No
	p,p'-DDT	10.29 ± 0.07	50	20	2.35×10^{-2}	Adult	1.17×10^{-3}	No
					1.41×10^{-1}	Child	7.05×10^{-3}	No
	Methoxychlor	9.02 ± 0.65	10	5	2.06×10^{-2}	Adult	4.12×10^{-3}	No
					1.24×10^{-1}	Child	2.47×10^{-2}	No
Lettuce	p,p'-DDT	2.20 ± 0.02	50	20	5.02×10^{-3}	Adult	2.51×10^{-4}	No
					3.01×10^{-2}	Child	1.51×10^{-3}	No
	γ-HCH	16.82 ± 4.80*	10	3	3.84×10^{-2}	Adult	1.28×10^{-2}	No
					2.30×10^{-1}	Child	7.68×10^{-2}	No
	δ-HCH	5.23 ± 0.09	10	3	1.19×10^{-2}	Adult	3.98×10^{-3}	No
					7.17×10^{-2}	Child	2.39×10^{-2}	No
	Aldrin	21.78 ± 1.19*	10	0.2	4.97×10^{-2}	Adult	2.49×10^{-1}	No
					2.98×10^{-1}	Child	1.49×10^{0}	Yes
Onion	Dieldrin	0.19 ± 0.13	10	0.2	4.34×10^{-4}	Adult	2.17×10^{-3}	No
					2.60×10^{-3}	Child	1.30×10^{-2}	No
	Endrin	1.21 ± 0.10	10	0.2	2.76×10^{-3}	Adult	1.38×10^{-2}	No
					1.66×10^{-2}	Child	8.29×10^{-2}	No
	p,p'-DDT	4.49 ± 1.45	50	20	1.03×10^{-2}	Adult	5.13×10^{-4}	No
					6.15×10^{-2}	Child	3.08×10^{-3}	No
	Methoxychlor	40.19 ± 2.38*	10	5	9.18×10^{-2}	Adult	1.84×10^{-2}	No
					5.51×10^{-1}	Child	1.10×10^{-1}	No
Soil	γ-HCH	0.09 ± 0.01	—	—	—	—	—	—
	β-HCH	5.60 ± 3.27	—	—	—	—	—	—
	p,p'-DDT	55.27 ± 6.91	—	—	—	—	—	—
	Methoxychlor	58.30 ± 3.11	—	—	—	—	—	—
Groundwater	β-HCH	0.50 ± 0.00	2.00	—	—	—	—	—
	p,p'-DDT	3.82 ± 0.02*	2.00	—	—	—	—	—

Note: mean ± standard deviation of 3 determinations; *above the EU/WHO MRL; for groundwater, WHO MRLs were used; for vegetables, EU MRLs were used; —, not applicable.

Table 7: Combined health and carcinogenic risks of multiple residues of organochlorine pesticide in vegetable samples.

Health risk	Farms	Cabbage		Lettuce		Onion	
		Adult	Children	Adult	Children	Adult	Children
Combined health risk	Ayigya	4.31×10^{-1}	2.59×10^{1}	4.31×10^{-1}	2.59×10^{1}	5.94×10^{-4}	3.56×10^{-3}
	Gyenyase	9.48×10^{-3}	5.69×10^{-2}	2.90×10^{-1}	1.74×10^{1}	2.50×10^{-1}	1.50×10^{1}
	Nsenie	—	—	3.49×10^{-1}	2.09×10^{1}	1.21×10^{-1}	7.27×10^{-1}
	Kentinkrono	3.77×10^{-2}	2.26×10^{-1}	3.95×10^{-1}	2.37×10^{1}	4.42×10^{-2}	2.65×10^{-1}
	Anglican Hostel	2.25×10^{-2}	1.35×10^{-1}	2.51×10^{-4}	1.51×10^{-3}	3.00×10^{-1}	1.80×10^{1}
Carcinogenic risk	Ayigya	7.79×10^{-9}	2.80×10^{-7}	4.54×10^{-7}	1.63×10^{-5}	5.29×10^{-9}	1.90×10^{-7}
	Gyenyase	4.24×10^{-8}	1.53×10^{-6}	2.98×10^{-7}	1.07×10^{-5}	2.60×10^{-7}	9.37×10^{-6}
	Nsenie	—	—	5.04×10^{-7}	1.81×10^{-5}	2.79×10^{-7}	1.00×10^{-5}
	Kentinkrono	1.20×10^{-7}	4.31×10^{-6}	5.11×10^{-7}	1.84×10^{-5}	2.76×10^{-8}	9.93×10^{-7}
	Anglican Hostel	5.73×10^{-8}	2.06×10^{-6}	3.90×10^{-9}	1.40×10^{-7}	3.85×10^{-8}	1.39×10^{-6}

Note: values >1 could potentially pose hazards to consumers.

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