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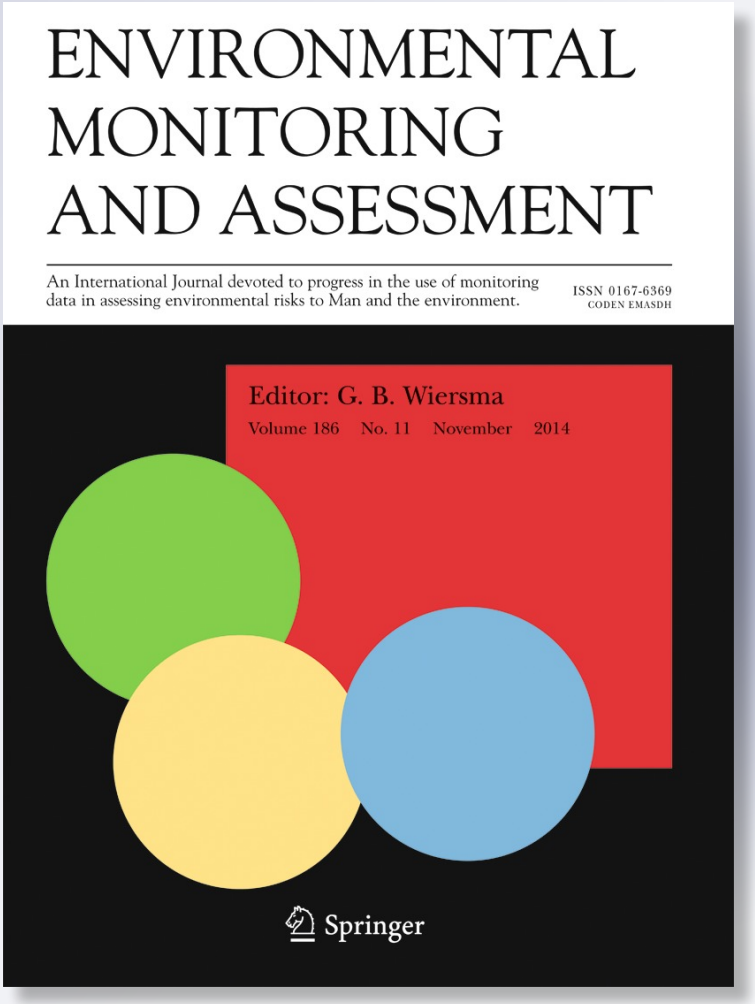

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Insecticide residues in soil and water in coastal areas of vegetable production in Togo

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Abstract Some common organochlorine, organophosphorus and pyrethroid insecticides were analysed in agricultural soil samples (n=35) and surface water and groundwater samples (n=25) collected from coastal areas of vegetable production in Togo. Analytical methods included solvent extraction of the insecticide residues and their subsequent quantification using GC-ECD. δ-HCH, heptachlor epoxide, 4,4-DDE, endosulphan (α, β and sulphate), lambda-cyalothrin and chlorpyrifos were found in the soil samples with concentrations that varied from non-detectable (ND) to 26.93 μg kg^{-1} dry weight. For water samples, heptachlor epoxide, 2,4-DDD, 4,4-DDD, 4,4-DDE and endosulphan (α, β, and sulphate) were found at contamination levels that varied from ND to 0.116 μg L^{-1}. The concentration of insecticide residues detected in the water samples was below the limits set by the World Health Organization (WHO) and also by the European Union (EU), with the exception of the concentration of endosulphan sulphate at the Aného site, which was 0.116 μg L^{-1}.

Keywords Insecticide residues · Water · Soil · Togo

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Introduction

Agriculture is Togo's most important economic sector, employing about two thirds of the labour force and contributing to 45 % of the gross domestic product (Anonymous 2010). Vegetable production is an informal employment sector and a fast growing economic activity, especially for women and unemployed youth. It is part of the country's poverty reduction strategy (Hounkpodoté and Tossou 2001) and agricultural diversification plan (Anonymous 2006). Pests are major limiting factors for vegetable production in Togo, and farmers usually rely on insecticides to protect their production due to limited knowledge and ability to manage pests and also due to high value of these vegetables. Although insecticide use has been found to be an immediate and cheap way to produce unblemished vegetables and increase yield, it has been associated with environmental contamination. For example, water contamination by insecticides has long been recognised as a major environmental impact associated with agriculture, due to the potential adverse effects on aquatic life and on humans if contamination extends to drinking waters (Skinner et al. 1997).

Insecticide use in coastal vegetable growing areas in Togo presents potential environmental hazards to the neighbouring population consuming the vegetables and

drinking water from nearby wells. A previous study in inland coffee and cotton areas showed that organochlorine residues were present in crops and groundwater exceeding the acceptable levels of the World Health Organization (WHO) (Mawussi et al. 2009). Because the soils used for growing vegetables in coastal areas are sandy, they are more susceptible to leaching and therefore pose a high risk to groundwater contamination by insecticides. The objective of this study was to quantify the extent of agricultural soil and water contamination by insecticides in coastal vegetable growing areas of Togo.

Materials and methods

The study area consisted of the following seven representative sites: Agbodrafo (N 6° 12.052′; E 1° 27.831); Aneho (N 06° 13.275′; E 1° 32.527′); Baguida (N 6° 09.977′; E 1° 19.050′); Bè (N 6° 07.976′; E 1° 15.399′); Fidokpui (N 6° 16.382′; E 1° 13.647′); Klobatemè (N 6° 14.720′; E 1° 15.252′); and Kpogan/Avepodzo (N 6° 10.652′; E 1° 22.666′) (Fig. 1). With the exception of Fidokpui and Klobatemè, all sites had very sandy soil (above 93 % of sand and below 3 % of clay), with an organic matter content of between 0.78 and 2.05 %. Sand, clay and organic matter contents were 28, 59 and 2.7 % for Fidokpui and 19, 68 and 2 % for Klobatemè sites, respectively.

The vegetable production area is dominated by small farms smaller than 0.2 ha on average. The main crops grown in 2012 were lettuce (*Lactuca sativa*), tomato (*Lycospersicum esculentum*), cabbage (*Brassica oleracea*), carrot (*Daucus carota*), pepper (*Solanum macrocarpum*), onion (*Allium ascalonicum*), long bean (*Vigna ungulculata*), cucumber (*Cucumis sativus*), eggplant (*Solanum melongena*), beet (*Beta vulgaris*), okra (*Abelmoschus esculentus*), amaranth (*Amaranthus gangeticus*) and mallow leaves (*Corchorus olitorius*).

At each of the seven sites, five composite soil samples (n=35) were collected from farmers' plots using a soil auger at 0–20-cm depth. Each composite soil sample was composed of 10 subsamples. Water samples (n=25) were collected from wells at depth between 5 and 12 m within the vegetable plots and in the vicinity of the Zio River using glass bottles (1 L). Each final water sample was a composite of five subsamples per sampling point. Water samples in glass bottles were refrigerated at 4 °C until extraction. Samples were analysed for 28 different insecticides including organochlorines (HCH and its four isomers, DDT and its four metabolites, endosulphan and its metabolite endosulphan sulphate, endrin, dieldrin, aldrin, heptaclor and its metabolite heptachlor epoxide, and pentachlorobenzene), pyrethroids (fenvalerate, deltamethrin and lambda-cyalothrin) and organophosphates (chlorpyriphos, profenophos, malathion, pirimiphos-methyl, fenitrotion, diazinon and dimethoate). The analytical standard of all insecticides had purities of between 97 and 99.5 %. Residues were extracted from water samples using a liquid-liquid partition method with dichloromethane (Mawussi et al. 2009). The extracts were filtrated through granular Na_2SO_4, evaporated with a rotary evaporator at 35 °C and recovered in hexane. For soil samples, residues were extracted using the shake flask method (Tor et al. 2006). Fifty grams of soil sample was suspended in 125 mL of petroleum ether+acetone (1:1 *v*/*v*) and shaken for 6 h. This process was repeated after adding another 125 mL of the same petroleum ether+acetone solution and shaking for 6 h more. After filtration using a vacuum pump system with a Buchner funnel and vacuum flask, the extracts were concentrated to 5 mL and stored at −20 °C until analysis.

The final extracts were analysed on a Varian CP 3800 gas chromatograph equipped with an electron capture detector (ECD). Operating conditions were capillary columns CP-Sil 8 CB and CP 1701 (30 m×0.25 mm internal diameter×0.25-μm film thickness), injection in splitless/split mode using 1 μL of sample, and oven temperatures were programmed as follows: starting temperature at 100 °C for 2 min, followed by a first ramp of 10 °C min^{-1} up to 150 °C, held for 1 min, and a second ramp at 5 °C min^{-1} up to 290 °C, held for 4 min. Injector and detector temperatures were 250 and 300 °C, respectively. A CP 1701 column was used for confirmation purposes. The carrier gas was nitrogen at a constant flow of 1 mL min^{-1}. Quantification of all insecticides was based on an external standard method, by comparing the peak area using calibration curves. Recoveries for the analysed insecticides ranged between 82 and 110 %, and residue data were not corrected for these recoveries. The limit of detection for all insecticides was 0.0009 μg L^{-1} for water samples and 0.0009 μg kg^{-1} for soil samples.

Results and discussion

Table 1 shows the levels of insecticide residues in 23 groundwater and surface water samples that represented

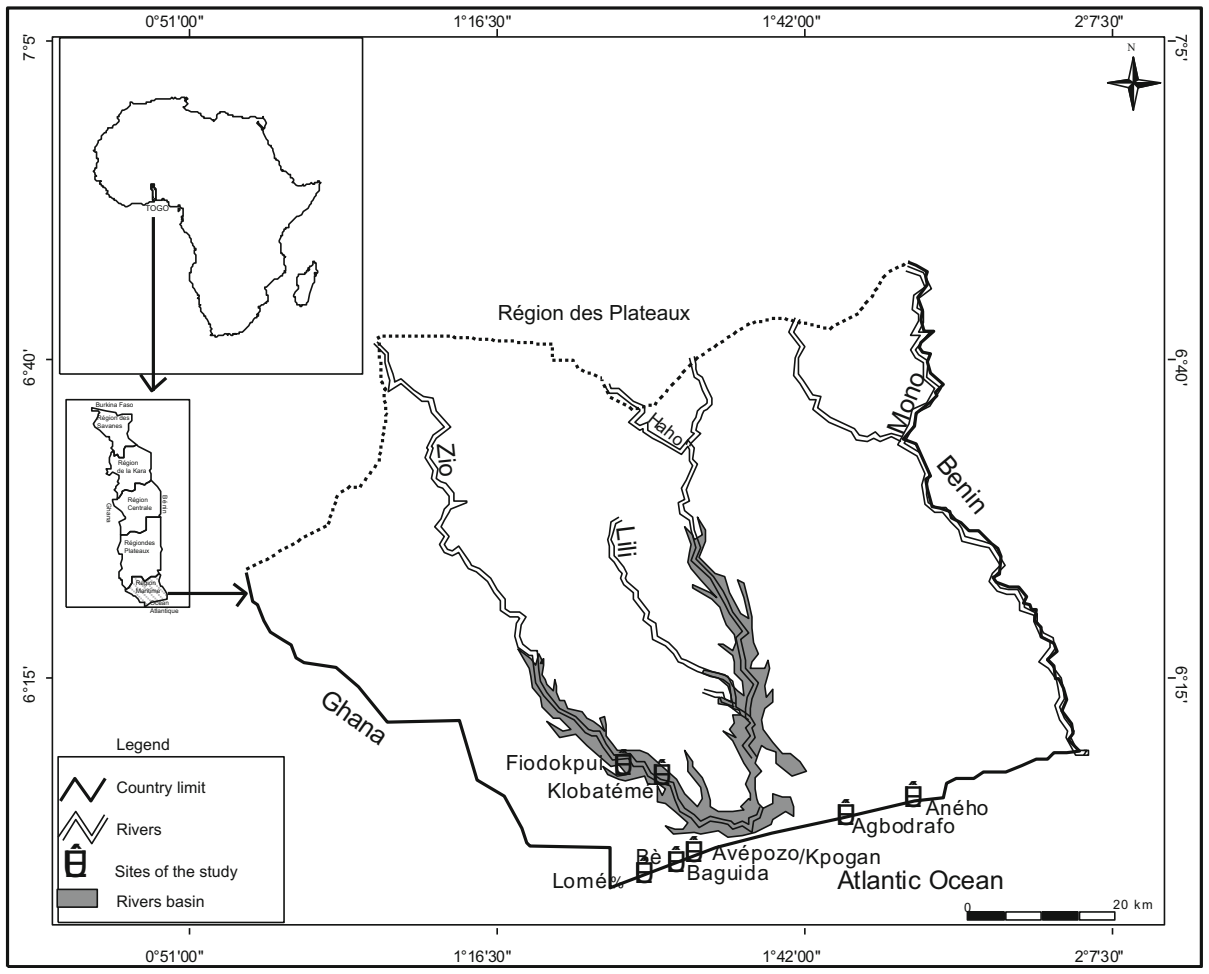

Fig. 1 Study area and the sampling sites

92 % of the total collected. Only in two groundwater samples from Fidokpui site were no insecticide residues detected. Qualitative analysis showed the presence of only organochlorine and its metabolites at various frequencies in these samples. The chemical 4,4-DDD was detected in 68 % of water samples, α-endosulphan in 64 %, endosulphan sulphate in 52 %, β-endosulphan in 16 %, heptaclor epoxide in 12 %, 4,4-DDE in 8 % and 2,4-DDD in 4 %. For some samples, we detected four different insecticide residues in groundwater (i.e. Baguida well 1) and even five in surface water (i.e. Zio River–Klomatèmè sampling point 2). Concentrations of 4,4-DDD ranged from 0.001 to 0.010 μg L^{-1}, α-endosulphan from 0.003 to 0.009 μg L^{-1}, endosulphan sulphate from 0.003 to 0.116 μg L^{-1}, β-endosulphan from 0.003 to 0.004 μg L^{-1}, heptaclor epoxide from 0.005 to 0.012 μg L^{-1}, 4,4-DDE from 0.003 to 0.005 μg L^{-1} and 2,4-DDD (with only one sample) at 0.009 μg L^{-1}.

About 77 % of soil samples were contaminated with at least one insecticide, and this included all seven sites considered in the study (Table 2). Qualitative analysis of soil samples showed the presence of six organochlorine residues at various frequencies, one organophosphorus, and one pyrethroid. Heptachlor epoxide was detected in 74 % of soil samples, δ-HCH in 41 %, 4,4-DDE in 37 %, chlorpyrifos in 11 %, α- and sulphate endosulphan and lambda-cyalothrin in 7 % and β-endosulphan in 4 %. In three soil samples of two sites (i.e. Baguida and Kpogan), we detected four different insecticide residues. The maximum contamination, with a concentration of 26.93 μg kg^{-1} dry weight, was due to chlorpyrifos at the Klobatèmè site. Concentrations of δ-HCH ranged from 0.053 to 4.88 μg kg^{-1} dry weight,

Table 1 Insecticide residues in groundwater and surface water (μg L^{-1})

Site		Well or sampling point	Insecticide residues in water (μg L^{-1})						
			Heptaclor epoxide	2,4-DDD	4,4-DDD	4,4-DDE	Endosulphan		
							α	β	Sulphate
Groundwater	Aného	1	ND	ND	ND	ND	ND	ND	0.116
		2	ND	ND	ND	ND	0.005	ND	0.009
	Avepozo	1	ND	ND	ND	ND	0.006	ND	ND
		2	ND	ND	ND	ND	0.004	ND	ND
		3	ND	ND	0.001	ND	0.007	0.003	ND
	Kpogan	1	ND	ND	0.004	ND	0.006	ND	0.005
		2	ND	ND	ND	ND	0.009	ND	0.016
		3	ND	ND	0.005	ND	ND	ND	0.023
		4	ND	ND	0.001	ND	0.004	ND	0.003
	Baguida	1	ND	ND	0.002	ND	0.005	0.004	0.011
		2	ND	ND	0.002	ND	0.007	0.003	ND
		3	ND	ND	ND	ND	0.006	0.003	0.003
		4	ND	ND	0.002	ND	0.007	ND	ND
	Klobatèmè	1	0.012	ND	0.008	ND	ND	ND	ND
		2	ND	ND	0.003	ND	ND	ND	0.010
		3	0.005	ND	0.007	ND	ND	ND	0.042
	Fidokpui	2	ND	ND	0.002	ND	ND	ND	ND
Surface water	Zio River–Klobatèmè	1	0.005	ND	0.002	ND	0.004	ND	ND
		2	ND	0.009	0.010	0.005	0.003	ND	0.003
		3	ND	ND	0.002	ND	0.006	ND	0.006
	Zio River–Fidokpui	1	ND	ND	0.009	ND	ND	ND	0.006
		2	ND	ND	0.003	ND	0.004	ND	ND
		3	ND	ND	0.002	0.003	0.005	ND	ND

ND below the detection limit (0.0009 μg L^{-1})

heptachlor epoxide from 0.613 to 6.837 μg kg^{-1} dry weight, 4,4-DDE from 0.388 to 2.288 μg kg^{-1} dry weight, α-endosulphan from 0.573 to 0.737 μg kg^{-1} dry weight, endosulphan sulphate from 0.943 to 1.2 μg kg^{-1} dry weight, lambda-cyalothrin from 1.889 to 3.728 μg kg^{-1} dry weight, chlorpyrifos from 0.556 to 26.93 μg kg^{-1} dry weight and β-endosulphan (with only one sample) at 0.611 μg kg^{-1} dry weight.

A comparison of types and concentrations of insecticide residues found in soils of different farmers' plots at each site would suggest substantial inter-farm variation in intensity of insecticide use. Moreover, no insecticide residues were detected in soil samples taken at certain places at the Agbodrafo, Aneho, Bè, Fidokpui and Klobatèmè sites.

In previous studies conducted in some of the study areas (Kanda 2003; Talaki 2005), it was revealed that the insecticides used were mostly organochlorines such as DDT, dieldrin, endrin, endosulphan, heptachlor, lindane and aldrin, and organophosphorus such as triazophos, profenofos, chlorpyriphos-ethyl and dimethoate. We observed in the data the illegal use of endosulphan in vegetable growing areas, given the fact that endosulphan is registered for use in cotton crop. The use of insecticides not registered for vegetables but other crops is not specific to Togo. The same observation has been made in Benin (Ton et al. 2000), Tchad, Central African Republic and Cameroon (Sougnabe et al. 2009).

Of the total of 28 different insecticides analysed, only 10 were detected in all soil and water samples. The mean

Table 2 Insecticide residues detected in soils of different sites and farmers' plots (μg kg^{-1} dry weight)

Site	Plot	Insecticide residues in soils (μg kg^{-1} dry weight)							
		δ-HCH	Heptachlor epoxide	4,4-DDE	Endosulphan			Lambda-cyalothrin	Chlorpyrifos
					α	β	sulphate		
Agbodrafo	1	1.519	1.079	ND	ND	ND	0.943	ND	ND
	2	ND	1.503	0.645	ND	0.611	ND	ND	ND
	3	ND	0.995	ND	ND	ND	ND	ND	ND
	5	1.131	0.613	ND	0.573	ND	ND	ND	ND
Aného	2	ND	1.739	ND	ND	ND	ND	ND	ND
	4	ND	4.242	ND	ND	ND	ND	ND	ND
	5	ND	1.996	ND	ND	ND	ND	ND	ND
Baguida	1	ND	0.846	0.388	ND	ND	ND	ND	ND
	2	ND	0.403	ND	ND	ND	ND	ND	ND
	3	1.254	1.068	ND	ND	ND	ND	ND	ND
	4	3.459	1.551	0.521	ND	ND	ND	ND	0.556
	5	1.276	0.868	0.391	ND	ND	ND	ND	ND
Be	1	2.514	2.299	ND	ND	ND	ND	ND	ND
	3	ND	3.412	ND	ND	ND	ND	ND	ND
	4	ND	6.837	ND	ND	ND	ND	ND	ND
	5	ND	1.107	ND	ND	ND	ND	ND	ND
Fidokpui	1	ND	ND	0.818	ND	ND	ND	ND	ND
	2	ND	ND	0.701	ND	ND	ND	ND	ND
	5	ND	ND	0.723	ND	ND	ND	ND	ND
Klobateme	1	4.244	2.423	ND	ND	ND	1.200	ND	ND
	4	3.142	2.159	ND	0.737	ND	ND	ND	ND
	5	0.053	ND	ND	ND	ND	ND	ND	26.930
Kpogan	1	3.570	2.855	ND	ND	ND	ND	1.889	2.763
	2	ND	ND	0.426	ND	ND	ND	ND	ND
	3	ND	ND	ND	ND	ND	ND	ND	0.816
	4	4.880	2.424	2.288	ND	ND	ND	3.728	ND
	5	ND	ND	0.501	ND	ND	ND	ND	ND

ND below the detection limit (0.0009 μg kg^{-1} dry weight)

concentrations of organochlorine insecticides detected in groundwater and surface water samples in this study were much lower than those detected in our previous studies (Mawussi et al. 2009) of water samples from coffee and cotton areas in Togo. This study found that 4,4-DDD was the most predominant metabolite of DDT in water samples (Table 1). It suggests that there may be a predominant degradation anaerobic pathway for DDT. Under anaerobic conditions, the first and major biotransformation product of DDT is DDD (Xu et al. 1994; Boul et al. 1994). On the other hand, 4,4-DDE was the only DDT metabolite detected in the soil samples. These results indicate the conversion of DDT to DDE under aerobic conditions. The major DDT metabolite in soil under normal aerated conditions is DDE (Aislabie et al. 1997).

The high level of endosulphan sulphate detected in water (i.e. 0.116 μg L^{-1}) implies that endosulphan has recently been used. The coastal area population including vegetable growers depend on well and river water for drinking and other domestic uses. Unfortunately, Togo does not have regulations on the maximum concentrations of insecticide residues in drinking water. Therefore, our results were compared with the maximum residue limits of 0.1 and 2 μg L^{-1} set by drinking water guidelines of the

European Union (EU) (European Commission 1991) and WHO (World Health Organization 2011), respectively. In this study, the concentration of insecticide residues detected in water samples was below the limits set by WHO and also by EU, with the exception of endosulphan sulphate at the Aného site, which had a concentration of 0.116 μg L^{-1}. Harnpicharnchai et al. (2013) carried out a similar study to assess organophosphate insecticide residues in soil, water and air of a vegetable growing area in Thailand and found chlorpyrifos maximum concentrations in soil of 32,193 μg kg^{-1}, which is much higher than the concentration of 26.930 μg kg^{-1} we found in our study. The extremely high concentrations of organophosphate insecticide residues in soil of vegetable growing area found by Harnpicharnchai et al. (2013) were attributed to a very intensive use.

Organochlorine insecticides were found in the soil and water samples analysed. Their use has been banned in Togo by the Ministerial Decree No. 31/MAEP/SG/DA of 21 September 2004 (Mawussi 2008). This study suggests the possibility of recent use of these very persistent insecticides or their extensive use in the past. The results of this study corroborate the findings of Dem et al. (2007), who found organochlorine insecticide residues in soil and water collected from cotton growing areas of Mali, West Africa. Similarly, in an investigation carried out by Ssebugerea et al. (2010) in southwestern Uganda, on monitoring of insecticide residues in soil from Kihiihi sub-county, Kanungu District, organochlorine insecticides were found (non-detectable [ND] to 59 μg kg^{-1}) in the analysed samples. A similar study conducted by Kihampa et al. (2010) in Tanzania, to assess the level of organochlorine insecticide residues in soil from tomato fields, revealed that DDT metabolites 4,4-DDD and 4,4-DDE were detected in 53 % of the soil samples analysed. A systematic review of studies done in Ghana, a neighbouring country of Togo, to give an integrated picture of agrochemicals, especially exposure of humans, animals, plants, water, soil, sediment and atmosphere, revealed contamination of the Ghanaian environment (Fianko et al. 2011). Numerous studies have reported the persistence of organochlorine insecticides in soil and water of cultivated land worldwide (Dem et al. 2007; Jamal 2011).

Conclusion

Various insecticides are extensively used in agricultural production in Togo to control pests, diseases, weeds and other plant pathogens, in an effort to reduce or eliminate yield losses and preserve high product quality. This study assessed the levels of 28 different insecticides including organochlorines (HCH and its four isomers, DDT and its four metabolites, endosulphan and its metabolite endosulphan sulphate, endrin, dieldrin, aldrin, heptachlor and its metabolite heptachlor epoxide and pentachlorobenzene), pyrethroids (fenvalerate, deltamethrin and lambda-cyalothrin) and organophosphates (chlorpyriphos, profenophos, malathion, pirimiphos-methyl, fenitrotion, diazinon and dimethoate) in soil, surface water and groundwater samples collected from coastal areas of vegetable production in Togo. Varied concentrations of 4,4-DDD, 4,4-DDE, 2,4-DDD, α-endosulphan, endosulphan sulphate, β-endosulphan, heptachlor epoxide, δ-HCH, lambda-cyalothrin and chlorpyrifos were found in the different samples. Although the use of organochlorine insecticides has been banned, our results show that they can still be detected in the environment. Their presence in the soil and their possible translocation into edible parts of crops suggest a need to investigate their presence in vegetable products.

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