



Dietary and ecological risk assessment of organochlorine pesticide residues in selected irrigated vegetables from Pankshin LGA, Plateau State, Nigeria

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ABSTRACT

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Pesticide poisoning remains a significant global public health issue, accounting for nearly 300,000 deaths annually. This study evaluated the concentrations and associated risks of eighteen organochlorine pesticide (OCP) residues in environmental media and five irrigated vegetables collected from Pankshin LGA, Plateau State, Nigeria, using gas chromatography–mass spectrometry (GC-MS). β -endosulfan was the only residue detected in water samples, whereas sixteen OCPs were identified in sediment. The majority of residues accumulated in the topsoil layer. Hazard quotient (HQ) values for soil exposure were generally below acceptable limits, except for γ -BHC via ingestion and dermal pathways. Children showed a higher likelihood of cancer risk through soil ingestion, while adults were more vulnerable via dermal contact and inhalation. Most pesticide residues in vegetables were below WHO maximum residue limits (MRLs), except for dieldrin, endrin aldehyde, and endrin ketone, with tomatoes showing the highest accumulation. Non-carcinogenic risk ($HQ < 1$) was observed for most residues; however, the hazard index (HI) for tomato exceeded unity, indicating potential health risks for both adults and children. Carcinogenic risk levels were above acceptable thresholds, particularly in children. These findings highlight the need for increased awareness and improved pesticide management practices among farmers and other stakeholders.

Contribution/Originality: This study contributes to the existing literature this study uses modified estimation methodology this study uses USEPA formula this study is one of very few studies that have investigated pesticide residue loads in the study area the paper contributes the first logical analysis on impact of pesticides residues on the environment and human health in the area.

1. INTRODUCTION

Pesticides have significantly contributed to agricultural productivity; however, their use poses serious risks to public health and the environment. One exceptional feature of pesticide use is that they are extremely poisonous chemicals and are willingly applied in the environment [1]. 'The trade, use and exposure to Highly Hazardous Pesticides (HHPs) in Nigeria are largely unmonitored and poorly regulated along the entire pesticide value chain, especially at the point of usage – farms, stores, warehouses, and institutions needing fumigation' [2]. Beyond acute toxicity, long-term exposure to pesticides has been linked to various health conditions, including cancer, neurological disorders, respiratory diseases, diabetes, reproductive abnormalities, and genetic defects [3]. The severity of these effects depends on both the level and route of exposure [4]. Globally, an estimated 1–5 million cases of pesticide poisoning occur annually, resulting in over 300,000 deaths, particularly among agricultural workers [2]. Although

developing countries account for only about 25% of global pesticide consumption, they experience approximately 99% of related fatalities, largely due to inadequate safety practices and limited awareness of toxicity risks [5].

In addition to controlling pests, many pesticides exhibit strong environmental persistence [1]. Their continuous use contributes to environmental degradation through contamination of soil, water, and food systems. This persistence may lead to reduced soil quality, groundwater pollution, development of resistant pest species, and broader ecological imbalance [1, 6].

Organochlorine pesticides (OCPs), such as DDT and aldrin, are particularly notable for their persistence and lipophilic nature, which promotes bioaccumulation in living organisms. Even at low concentrations, these compounds can accumulate in fatty tissues, posing long-term health risks [7]. In Britain, it was discovered that male workers in Organochlorine insecticide factory had temporarily lost their potency for months after exposure to the chemicals, while it was estimated that over 10,000 people die annually in third-world countries, including Nigeria, from pesticide accidents [8]. Also, in Malwa village, where OCP was used extensively as a pesticide in cotton farming reported 46% of the total 34,430 cancer deaths in the whole state of Punjab India. Though OCP was banned, its implementation is in most developed countries; developing countries widely use it due to its efficacy, low cost and possibly due to weak import control and lack of logistics to monitor pesticides [9, 10]. The aim of this paper is to assess the dietary and ecological risks of 18 OCP residues in water, sediment, soil and vegetables and their health and environmental impacts.

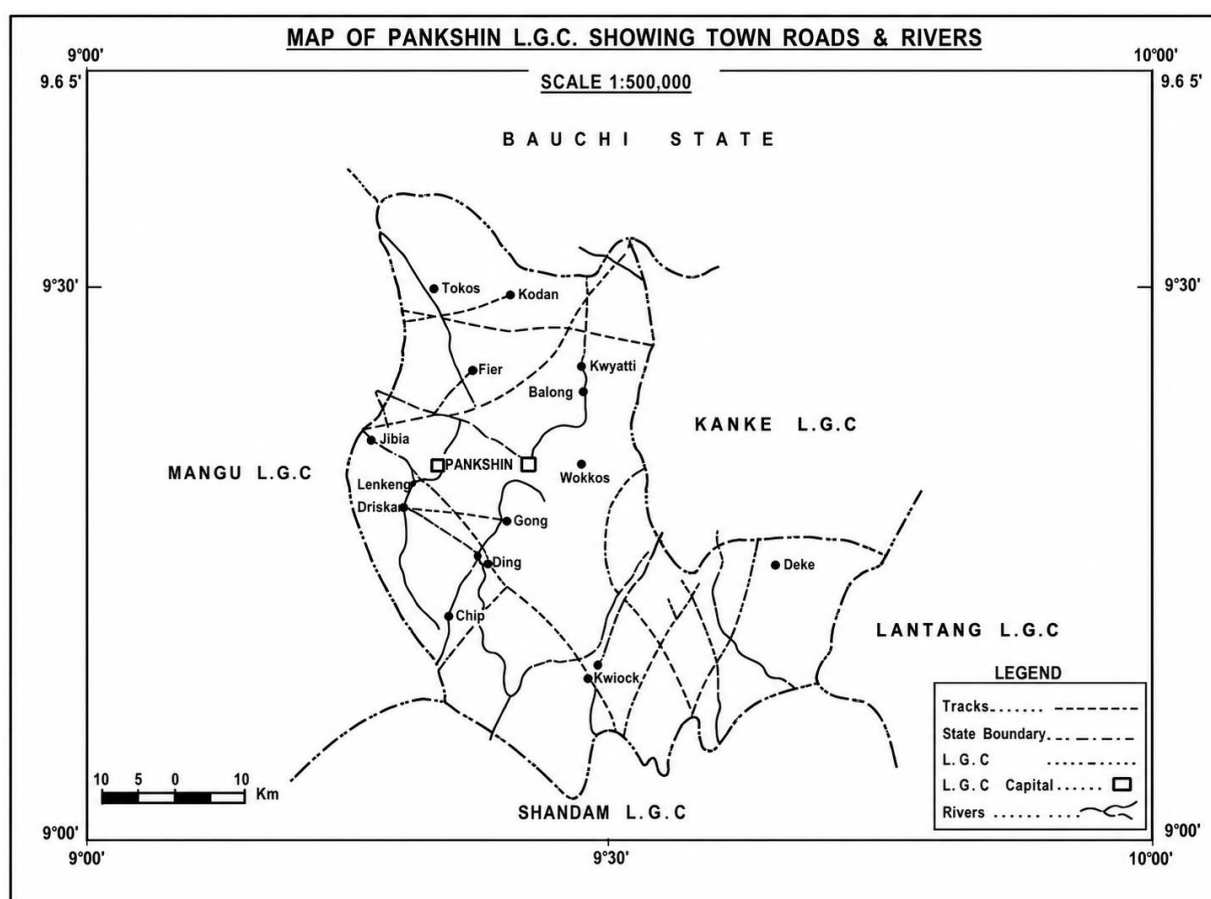


Figure 1. Map of Pankshin Local Government Area showing the different Districts.

Source: Mohammed and Katwal [11].

2. MATERIALS AND METHODS

2.1. Study Area

Pankshin Local Government Area is located in Plateau State (Figure 1), Nigeria, covering approximately 1,524 km² with a population of about 191,685 based on the 2006 census. The area is predominantly agrarian, with farmers cultivating crops such as millet, maize, rice, tomatoes, cabbage, onions, and various fruits. The region experiences a relatively temperate climate, with temperatures ranging between 13°C and 22°C. The coldest period occurs during the harmattan season (December–February), while the highest temperatures are recorded between March and April. Annual rainfall ranges from approximately 131.75 cm to 146 cm [11].

2.2. Sample Collection

Soil samples were collected from irrigated farmlands at three depths (0–10 cm, 11–20 cm, and 21–30 cm) using a spiral auger. Samples from each depth were composited, properly labeled, and transported to the laboratory. Sediment samples were obtained from nearby water bodies where water samples were also collected. Five types of vegetables tomato (*Lycopersicon esculentum*), potato (*Solanum tuberosum*), green beans (*Phaseolus vulgaris*), green pepper (*Capsicum annum*), and cabbage (*Brassica oleracea*) were randomly collected from multiple locations within irrigated sites. Samples from each vegetable type were combined to form composite samples, sealed in labeled polyethylene bags, and stored at –4°C prior to analysis.

2.3. Extraction of Pesticide Residues from Water

Pesticide residues in water samples were extracted using a liquid–liquid extraction method. One liter of filtered water was transferred into a separating funnel and extracted with 50 mL of n-hexane. The mixture was shaken and allowed to separate. The organic phase was collected, and the aqueous phase was re-extracted twice with fresh solvent. The combined organic extracts were dried using anhydrous sodium sulfate and concentrated using a rotary evaporator.

2.4. Extraction from Soil and Sediment

Approximately 10 g of soil or sediment sample was placed in a pre-cleaned extraction thimble and subjected to Soxhlet extraction using a mixture of n-hexane and acetone (4:1 v/v) for 8 hours. The extract was concentrated to dryness, reconstituted in n-hexane, and prepared for clean-up procedures.

2.5. Extraction from Vegetable Samples

Vegetable samples were processed using the USEPA 3510 extraction method with ethyl acetate as the solvent. Samples were washed, homogenized, and dehydrated using anhydrous sodium sulfate. The homogenized sample was extracted with ethyl acetate, followed by the addition of sodium hydrogen carbonate and further sodium sulfate. The mixture was shaken thoroughly, filtered, and centrifuged. The organic layer was separated and further processed for analysis (Daniel, Charles, & Dass, 2021).

2.6. Sample Clean-Up

Silica gel was activated at 130°C for 16 hours and used for column clean-up. Extracts were passed through the column, eluted with appropriate solvents, and concentrated to a final volume suitable for analysis.

2.7. GC-MS Analysis of OCPs

Quantification of organochlorine pesticides was performed using gas chromatography–mass spectrometry (GC-MS). Calibration standards were prepared from a stock solution containing 18 OCPs. The GC-MS system operated under optimized conditions, including selective ion monitoring (SIM) and scan modes for accurate detection.

Separation was achieved using an HP-5 capillary column, with helium as the carrier gas. Samples were injected in splitless mode, and detection was carried out under electron-impact ionization. The instrument was calibrated prior to analysis, and concentrations of OCPs were determined accordingly [12].

2.8. Health Risk Assessment

Human exposure to soil contaminants occurs through ingestion, dermal contact, and inhalation. In this study, risk assessment was conducted by calculating the lifetime average daily dose (LADD), hazard quotient (HQ), and incremental lifetime cancer risk (ILCR), following USEPA guidelines. LADD values were determined for each exposure pathway, while HQ was used to evaluate non-carcinogenic risks by comparing exposure levels to reference doses. Carcinogenic risks were estimated using cancer slope factors (CSF) and inhalation unit risks. These indices were used to assess potential health implications associated with exposure to pesticide-contaminated soils [13–15].

2.9. Statistical Analysis

All samples were analyzed in triplicate, and the mean values were calculated. Statistical analysis was conducted using SPSS version 23.0 for Windows. Data normality was assessed using the Kolmogorov–Smirnov one-sample test. Where necessary, logarithmic transformation was applied to ensure homogeneity of variance. Significant differences between means were evaluated using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test, with statistical significance set at $p < 0.05$. Relationships among quantitative variables were determined using Pearson's correlation coefficient (r).

Table 1. Concentration of pesticide residues (OCP) detected in water (mg/l), sediment and soil at three depths (mg/kg) around Pankshin irrigated areas.

Pesticide residue	PKNW	PKNS	PKN1	PKN2	PKN3	WHO MRL
α -BHC	0	0	0	0	0.03	2
β -BHC	0	0.08	0.03	0	0	2
γ -BHC	0	7.5	78829.03	0	4.93	2
δ -BHC	0	0.05	0.05	0.05	0.03	2
Heptachlor	0	0.3	0.03	0	0.1	0.03
Aldrin	0	0.2	0.33	0	0.23	
Heptachlor epoxide	0	0	0	0	0	
α -Endosulfan	0	0.45	0.15	0	0.43	0.01
Dieldrin	0	0.7	0.1	0	0.05	0.03
p,p'-DDE	0	0.18	0.03	0	0.03	2
Endrin	0	1.08	0.53	0	0.68	
β -Endosulfan	0.13	0.38	0.08	0.08	0.15	
p,p'-DDD	0	0.03	0.00	0	0.05	2
Endrin Aldehyde	0	0.1	0.58	0	0.53	0.01
p,p'-DDT	0	0.18	0.05	0	0.1	2
Endosulfan Sulphate	0	0.08	0.03	0	0.25	0.01
Endrin ketone	0	17.43	3.45	0	4.13	
Methoxychlor	0	0.18	0.05	0	0.23	2

Note: Key: PKN= Pankshin; 1= soil 0 – 10cm, 2 = 11 – 20cm, 3 = 21–30 cm, and the predicted no-effect concentration (PNEC) value for β -endosulfan is 0.028 in water [16].

3. RESULTS AND DISCUSSION

3.1. OCP Residues in Water, Sediment, and Soil

The distribution of organochlorine pesticide (OCP) residues in water, sediment, and soil samples from Pankshin is presented in Table 1. Among the analyzed compounds, β -endosulfan was the only residue detected in water. Its presence may be attributed to agricultural runoff, direct discharge, or re-suspension from contaminated sediments. The relatively higher solubility of β -endosulfan compared to its isomers likely explains its preferential partitioning

into the aqueous phase [17]. The Risk quotient (RQ) for the γ -BHC residues detected in water was greater than one for the area, indicating the likelihood of causing adverse effects to biota [18].

In contrast, the majority of OCP residues were detected in sediment samples, indicating that sediments serve as major reservoirs for these persistent pollutants. Lawrence, et al. [19] found lower α -BHC but the highest concentration (2.4 $\mu\text{g/kg dw}$) in Ogbesse River in Edo State. Most compounds were present below threshold effect levels (Table 2); however, certain residues such as endrin, dieldrin, and γ -HCH exceeded established sediment quality guidelines, suggesting moderate to significant ecological risk. These contaminants may be remobilized under changing environmental conditions, posing potential threats to aquatic organisms [19, 20].

Table 2. Sediment quality guidelines.

Compound	ERL	ERM	TEL	PEL	Measured Concentration
γ -HCH	-	-	0.94	1.38	75.30
Σ HCHs	-	-	-	-	78829.11
p,p'-DDD	2	20	3.54	8.51	0.00
p,p'-DDE	2.2	27	1.42	6.75	0.03
p,p'-DDT	1	7	1.79	-	0.05
DDTs	1.58	46.1	7	44.50	0.08
Dieldrin	0.02	82	8	2.85	0.1
Endrin	0.02	45	2.67	62.4	0.53
Heptachlor epoxide	-	-	0.6	2.74	0

Source: Chen, et al. [20].

Note: ERL: effects range-low; effects range-median (ERM); threshold effects level (TEL); probable effects level (PEL).

Soil analysis revealed that OCP residues were predominantly concentrated in the topsoil layer (0–10 cm) (Table 1), highlighting recent application (Surface deposition) or metabolite degradation. The observed ratios of pesticide metabolites suggest both historical and ongoing usage of these chemicals. For instance, higher levels of DDE or DDD relative to DDT indicate aerobic or anaerobic degradation of DDT, while elevated aldrin concentrations compared to dieldrin suggest recent inputs [14]. The high concentration of aldrin, in comparison with dieldrin, confirms its fresh input in the study area and γ -BHC highest concentration among the BHCs indicates that the HCHs sources could have emanated from the use of lindane or could be linked to the use of technical HCHs. Technical HCH is primarily composed of α -HCH (60–70%), β -HCH (5–12%), γ -HCH (10–15%), δ -HCH (6–10%), and lindane γ -HCH (99%). 'In aged environmental samples, α -HCH and γ -HCH can be changed to β -HCH, which is more persistent in the environment compared to other HCH isomers' [15].

3.2. Human Health Risk from Soil Exposure

The calculated lifetime average daily dose (LADD) values for ingestion, dermal contact, and inhalation pathways (Table 3) were generally low for both adults and children, except for γ -BHC, which exhibited elevated exposure levels across all pathways.

Table 3. Lifetime average daily dose (LADD) values for each OCP for three exposure pathways.

Pesticide residue	LADD Ing		LADD Der		LADD Inh		ADI
	C	A	C	A	C	A	
α -BHC	0.0	0.00	-	-	0.00	0.00	3
β -BHC	1.23E-4	1.02E-4	-	-	2.0E-7	7.0E-7	3
γ -BHC	323.20	268.02	118.24	1379.51	4.09E-1	1.81	3
δ -BHC	2.05E-4	1.70E-04	-	-	2.0E-7	7.0E-7	3
Heptachlor	1.23E-4	1.02E-4	-	-	2.0E-7	7.0E-7	0.1
Aldrin	1.35E-3	1.12E-3	-	-	2E-6	8E-6	0.2
Heptachlor epoxide	0.00	0.00	-	-	-	-	0.1
α -Endosulfan	6.15E-4	5.10E-4	2.25 E-3	2.65E-3	1.0E-6	3.0 E-6	6

Dieldrin	4.10E-4	3.4E-4	-	-	1.0E-6	2.0E-6	0.2
p,p'-DDE	1.23E-4	1.02E-4	-	-	2.0E-7	7.0E-7	20
Endrin	2.17E-3	1.80E-3	-	-	3.0E-5	1.2E-5	0.2
β-Endosulfan	3.28E-4	2.72E-4	1.20E-4	1.40E-3	4.0E-7	2.8E-7	6
p,p'-DDD	0.00	0.00			0.00	0.00	20
Endrin Aldehyde	2.38E-3	1.97E-3			3E-6	1.3E-5	0.2
p,p'-DDT	2.05E-4	1.70E-4	7.5E-5	8.75E-5	3.0E-7	1.2E-6	20
Endosulfan Sulphate	1.23E-4	1.02E-4	4.5E-5	5.25E-4	2.0E-6	7E-7	6
Endrin ketone	1.41E-2	1.17E-2			1.8E-5	7.9E-5	0.2
Methoxychlor	2.05E-4	1.70E-4			3E-7	1.2E-6	5

Note: Key: LADD = Lifetime average daily dose, Ing = Ingestion, Der = Dermal, Inh = Inhalation, A = Adults; C = Children.

From the results, the average exposure dose of the three exposure pathways for both adults and children are observed to increase in the order of LADD inh < LADD dermal < LADD ing. Hazard quotient (HQ) values (Table 4) for most residues were below the acceptable threshold ($HQ < 1$), indicating minimal non-carcinogenic risk. This is in agreement with the work of Liu, et al. [21]. However, γ-BHC exceeded safe limits, particularly through ingestion and dermal exposure, suggesting potential health concerns. The HI of the inhalation pathway was the only one below one.

Table 4. The hazard quotients and risk indices for OCP residues for three exposure pathways.

Pesticide residue	HQ Ing		HQ der		HQ Inh	
	C	A	C	A	C	A
α-BHC	-	-	-	-	-	-
β-BHC	6.15E-05	5.10E-05	0	0	7.80E-08	3.45E-07
γ-BHC	161.6	134.01	59.12	689.75	0.2	0.91
δ-BHC	1.03E-04	8.50E-05	0	0	1.30E-07	5.75E-07
Heptachlor	6.15E-05	5.10E-05	0	0	7.80E-08	3.45E-07
Aldrin	-	-	-	-	-	-
Heptachlor epoxide	-	-	-	-	-	-
α-Endosulfan	6.15E-03	5.10E-03	2.25E-03	2.63E-02	7.80E-06	3.45E-05
Dieldrin	1.37E-03	1.13E-05	0	0	1.73E-06	7.67E-06
p,p'-DDE	6.15E-05	5.10E-05	0	0	7.80E-08	3.45E-07
Endrin	-	-	-	-	-	-
β-Endosulfan	-	-	-	-	-	-
p,p'-DDD	0	0	0	0	0	0
Endrin Aldehyde	0.24	0.29	0	0	3.02E-04	1.33E-03
p,p'-DDT	1.03E-04	8.55E-05	3.75E-05	4.38E-04	1.30E-07	5.75E-07
Endosulfan Sulphate	0.12	0.12	0.05	0.53	1.56E-04	6.90E-04
Endrin ketone	7.07E-03	5.87E-03	0	0	8.97E-06	3.97E-05
Methoxychlor	1.03E-04	8.55E-05	0	0	1.30E-07	5.75E-07
HI	161.98	134.43	59.17	690.31	0.20	0.91

Note: HQ = Hazard quotient, HI = Hazard Index, Ing = Ingestion, Der = dermal, Inh = Inhalation, A = Adults, C = Children.

The incremental lifetime cancer risk (ILCR) assessment (Table 6) calculated using the slope factors (Table 5) revealed that cumulative cancer risk values exceeded the acceptable limit (10^{-6} - 10^{-4}), indicating a potential carcinogenic threat. Children were more vulnerable via ingestion, whereas adults exhibited higher risks through dermal and inhalation exposure pathways.

Table 5. The cancer slope factors for calculating the incremental cancer risk (ILCR) for humans exposed to environmental pollutants.

Pesticide residue	CSF Ingestion	CSF Dermal	CSF Inhalation
α-BHC	6.30	4.49	6.30
β-BHC	1.80	1.98	1.86
γ-BHC	1.30	1.34	1.80

δ -BHC	1.80	N/A	1.80
Heptachlor	4.5		
Aldrin	1.7		
Heptachlor epoxide			
α -Endosulfan			
p,p'-DDT	3.40×10^{-1}	4.86×10	3.40×10^{-1}
Dieldrin	1.6		
p,p'-DDE	3.40×10^{-1}	4.86×10^{-1}	N/A
Endrin			
β -Endosulfan			
p,p'-DDD	2.40×10^{-1}	3.43×10^{-1}	N/A
Endrin Aldehyde			
p,p'-DDT	3.40×10^{-1}	4.86×10^{-1}	3.40×10^{-1}
Endosulfan Sulphate			

Source: Mungai and Wang [15].

Table 6. Cancer risks related to farmer exposure to OCP residues in the irrigated surface soil from Pankshin.

Pesticide residues	Ingestion		Dermal		Inhalation	
	CR C	CR A	CR C	CR A	CR C	CR A
α -BHC	-	-	-	-	-	-
β -BHC	$2.2\text{E-}4$	$1.8\text{E-}4$	$2.2\text{E-}4$	$2\text{E-}4$		
γ -BHC	420.16	348.42	158.45	1848.54	2.58	11.42
δ -BHC	$3.7\text{E-}4$	$3.1\text{E-}4$	-	-	$4.7\text{E-}7$	$2.1\text{E-}5$
Heptachlor	$5.5\text{E-}4$	$4.6\text{E-}4$	-	-	-	-
Aldrin	$2.30\text{E-}4$	$1.91\text{E-}4$	-	-	-	-
Heptachlor epoxide	-	-	-	-	-	-
α -Endosulfan	$3.87\text{E-}3$	$3.21\text{E-}3$	-	-	-	-
Dieldrin	$6.6\text{E-}4$	$5.4\text{E-}4$	-	-	-	-
p,p'-DDE	$4.0\text{E-}5$	$3.0\text{E-}5$	$2.19\text{E-}5$	$2.55\text{E-}4$	-	-
Endrin	$1.37\text{E-}2$	$1.14\text{E-}2$	-	-	-	-
β -Endosulfan	$2.07\text{E-}3$	$1.71\text{E-}3$	-	-	-	-
p,p'-DDD	0.00	0.00	-	-	-	-
Endrin Aldehyde	$1.5\text{E-}2$	$1.24\text{E-}2$	-	-	-	-
p,p'-DDT	$6.97\text{E-}5$	$5.78\text{E-}5$	$3.65\text{E-}5$	$4.253\text{E-}4$	$1\text{E-}7$	$4\text{E-}7$
Endosulfan Sulphate	$2.2\text{E-}3$	$1.8\text{E-}4$	-	-	-	-
Endrin ketone	-	-	-	-	-	-
Methoxychlor	-	-	-	-	-	-

Note: Key: CR = Cancer risks, C = Children, A = Adults.

3.3. OCP Residues in Vegetables

The concentrations of OCP residues in vegetables varied across crop types (Table 7). Among the analyzed samples, tomato accumulated the highest levels of most pesticide residues, including aldrin, dieldrin, endrin aldehyde, and endrin ketone.

Table 7. Mean concentrations in mg/kg of pesticide residues in vegetables.

Pesticide residue	PKNT	PKNP	PKNGB	PKNGP	PKNCa	MRL (W.H.O)
α -BHC	0.025	0.025	0.025	0	0.45	10
β -BHC	0.175	0	0.025	0	0.425	10
γ -BHC	5.925	8.225	2.475	0	6.125	10
δ -BHC	0.025	0.025	0.05	0	0.15	10
Heptachlor	0.05	0	0.125	0.025	0.175	10
Aldrin	41.73	0.1	0.225	0	0.625	10
Heptachlor epoxide	0	0	0	0	0.1	10
α -Endosulfan	0.425	0.025	0.5	0.225	1.075	10
Dieldrin	528.08	0.1	0.275	0	0.725	10
p,p'-DDE	0.5	0	0.075	0	0.125	50

Endrin	15.75	0.3	2.425	0	0.375	10
β -Endosulfan	1.03	0.425	0.15	0.35	0.25	10
p,p'-DDD	0.375	0	0.05	0	0.075	50
Endrin Aldehyde	246.75	0.15	0.275	0.125	0.875	10
p,p'-DDT	0.2	0.025	0.025	0	0.075	50
Endosulfan Sulphate	1.4	0	0.525	0.075	0.25	10
Endrin ketone	19515.73	1.05	2.7	1.1	3.8	10
Methoxychlor	0	0.025	0.175	0.1	0.1	10

Note: **Key:** PKN = Pankshin T = Tomato, P = Potato, GB=Green beans, GP=Green pepper, Ca= Cabbage. Maximum Residue Level

The results in Table 7 show the levels of OCPs in five vegetables. The BHC residues in the vegetables' ranges were: α -BHC, ND – 0.45 mg/kg; β -BHC, ND- 0.425 mg/kg; γ -BHC, ND – 8.225 mg/kg and δ -BHC, ND - 0.15 mg/kg. γ -BHC had an exceptionally high concentration value of 8.225 mg/kg in potato, which could be due to the application of fresh lindane. The ranges of Heptachlor residue were from ND – 0.175 mg/kg and hept-epoxide was only detected in cabbage (0.1 mg/kg). The concentrations of aldrin and dieldrin ranged from 0.1-41.73 mg/kg and ND – 528.08 mg/kg, respectively, with tomato accumulating the highest concentration above the MRL values. α -endosulfan, β -endosulfan and endosulfan sulfate have concentration levels ranging from 0.025 – 1.075 mg/kg, 0.15- 1.03 mg/kg and ND - 1.4 mg/kg, respectively with α -Endosulfan having the highest exceptional concentration of 1.03 mg/kg in tomato. Endrin, endrin aldehyde and endrin ketone with concentrations of ND – 15.75 mg/kg, 0.15– 246.75 mg/kg and 1.1– 19515.73 mg/kg, respectively with all having concentrations above the MRL values in tomato. The concentration ranges of DDE, DDD and DDT were: ND – 0.5 mg/kg, ND – 0.375 mg/kg, ND – 0.2 mg/kg, respectively. Methoxychlor had a concentration range of ND - 0.175 mg/kg. While most detected residues were within the permissible limits established by regulatory bodies, certain compounds—particularly dieldrin, endrin aldehyde, and endrin ketone, exceeded maximum residue limits (MRLs). The elevated concentration of γ -BHC in potatoes suggests possible recent application of lindane-based pesticides.

3.4. Dietary Exposure and Risk Assessment

Estimated Daily Intake (EDI) values for most pesticide residues were below Acceptable Daily Intake (ADI) thresholds (Table 8). However, exceptions were observed for aldrin, dieldrin, endrin aldehyde, and endrin ketone in tomatoes, where intake levels exceeded recommended limits for both adults and children.

Table 8. Estimated Daily Intake (EDI) of OCP Residues in five vegetables for children and adults from Pankshin.

Pesticide Residue	EDI Children					EDI Adults					ADI
	PKNT	PKNP	PKNGB	PKNGP	PKNCa	PKNT	PKNP	PKNGB	PKNGP	PKNCa	
α -BHC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3
β -BHC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3
γ -BHC	0.04	0.06	0.02	0.00	0.04	0.03	0.05	0.01	0.00	0.04	3
δ -BHC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3
Heptachlor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1
Aldrin	0.30	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.2
Heptachlor epoxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1
α -Endosulfan	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	6
Dieldrin	3.74	0.00	0.00	0.00	0.01	3.04	0.00	0.00	0.00	0.00	0.2
p,p'-DDE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20
Endrin	0.11	0.00	0.02	0.00	0.00	0.09	0.00	0.01	0.00	0.00	0.2
β -Endosulfan	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	6
p,p'-DDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20
Endrin Aldehyde	1.75	0.00	0.00	0.00	0.01	1.42	0.00	0.00	0.00	0.01	0.2
p,p'-DDT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20
Endosulfan Sulphate	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	6
Endrin ketone	138.37	0.01	0.02	0.01	0.03	112.22	0.01	0.02	0.01	0.02	0.2
Methoxychlor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5

Table 9. Hazard Quotients of OCP Residues via ingestion for five vegetables for children and adults from Pankshin.

Pesticide residue	HQ C					HQ A				
	PKNT	PKNP	PKNGB	PKNGP	PKNCa	PKNT	PKNP	PKNGB	PKNGP	PKNCa
α -BHC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
β -BHC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
γ -BHC	0.01	0.02	0.01	0.00	0.01	0.01	0.02	0.00	0.00	0.01
δ -BHC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heptachlor	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01
Aldrin	1.48	0.00	0.01	0.00	0.02	1.20	0.00	0.01	0.00	0.02
Heptachlor epoxide	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
α -Endosulfan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dieldrin	18.72	0.00	0.01	0.00	0.03	15.18	0.00	0.01	0.00	0.02
p,p'-DDE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Endrin	0.56	0.01	0.09	0.00	0.01	0.45	0.01	0.07	0.00	0.01
β -Endosulfan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p,p'-DDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Endrin Aldehyde	8.75	0.01	0.01	0.00	0.03	7.09	0.00	0.01	0.00	0.03
p,p'-DDT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Endosulfan Sulphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Endrin ketone	691.8	0.04	0.10	0.04	0.13	561.1	0.03	0.08	0.03	0.11
Methoxychlor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HI	721	0.08	0.23	0.05	0.27	585.0	0.07	0.18	0.04	0.22

Note: HQ = Hazard quotient, A =Adults, C= Children.

Hazard quotient (HQ) analysis showed that most residues posed negligible risk ($HQ < 1$) (Table 9), except for the aforementioned compounds, which contributed significantly to overall exposure. The cumulative hazard index (HI) was below unity for most vegetables, indicating low combined risk.

However, tomato exhibited HI values greater than 1 for both adults and children, suggesting potential non-carcinogenic health risks associated with its consumption. Notably, children were found to be more susceptible to exposure due to higher intake relative to body weight.

3.5. Carcinogenic Risk from Vegetable Consumption

The carcinogenic risk assessment revealed that OCP residues in vegetables exceeded acceptable risk levels. The risk was consistently higher in children than in adults.

Table 10. Carcinogenic risks of OCP residues in five selected vegetables for children and adults.

Pesticide Residue	Carcinogenic risks (Children)					Carcinogenic risks (Adults)				
	PKNT	PKNP	PKNGB	PKNGP	PKNCa	PKNT	PKNP	PKNGB	PKNGP	PKNCa
α -BHC	1.11E-03	1.12E-3	1.12E-3	0	2.0E-2	9.1E-4	9.06E-4	9.1E-4	0	1.6E-2
β -BHC	2.23E-03	0	3.19E-4	0	5.4E-3	1.8E-3	0	2.6E-4	0	4.4E-3
γ -BHC	5.46E-02	7.58E-2	2.28E-2	0	5.6E-2	4.4E-2	6.15E-2	1.9E-2	0	4.6E-2
δ -BHC	3.19E-04	3.19E-4	6.38E-4	0	1.9E-3	2.6E-4	2.59E-4	5.2E-4	0	1.6E-3
Heptachlor	1.59E-03	0	3.99E-3	8.0E-4	5.6E-3	1.3E-3	0	3.2E-3	6.5E-4	4.5E-3
Aldrin	5.02E-01	1.21E-3	2.71E-3	0	7.5E-3	4.1E-1	9.78E-4	2.2E-3	0	6.1E-3
Dieldrin	5.99E+00	1.13E-3	3.12E-3	0	8.2E-3	4.86	9.2E-4	2.5E-3	0	6.7E-3
p,p'-DDE	1.21E-03	0	1.81E-3	0	3.0E-4	9.8E-4	0	1.5E-4	0	2.4E-4
p,p'-DDD	6.38E-04	0	8.51E-05	0	1.3E-4	5.2E-4	0	6.9E-5	0	1.0E-4
p,p'-DDT	4.82E-04	6.02E-05	6.027E-05	0	1.8E-4	3.9E-4	4.9E-5	4.9E-5	0	1.5E-4

Among the vegetables studied as shown in Table 10, tomato presented the highest carcinogenic risk, followed by potatoes and cabbage. Exposure to these residues may increase the likelihood of developing cancer-related conditions, particularly with prolonged consumption.

4. CONCLUSION

This study demonstrates that organochlorine pesticide residues are prevalent in soil, sediment, and commonly consumed vegetables from irrigated areas of Pankshin, Plateau State. The highest concentrations were observed in surface soils, indicating recent or continuous pesticide application. Certain residues, particularly dieldrin, endrin aldehyde, and endrin ketone, exceeded recommended safety limits in vegetables, especially in tomatoes. Risk assessment results indicated that these compounds contribute significantly to both non-carcinogenic and carcinogenic health risks, with children being more vulnerable than adults.

Although the majority of residues were within acceptable limits, the cumulative effects and potential for bioaccumulation raise concerns regarding long-term exposure. Therefore, continuous monitoring of pesticide residues in food crops is essential. In addition, stricter regulatory enforcement, improved pesticide management practices, and increased public awareness, particularly among farmers are strongly recommended to mitigate potential health and environmental risks.

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