



Occurrence and health risk of organochlorine pesticides in coastal creeks of Ondo State, Nigeria

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Abstract

Organochlorine pesticides (OCPs) are persistent, hydrophobic contaminants that bioaccumulate in aquatic ecosystems, posing ecological and human health concerns. This study investigated the occurrence, distribution, and health risks of OCPs in water, sediment, and silver catfish (*Chrysichthys nigrodigitatus*) from selected coastal creeks in Ondo State, Nigeria. OCP concentrations were determined using gas chromatography, while human health risks were evaluated using non-carcinogenic and carcinogenic hazard indices. Seventeen OCP congeners were detected in surface water (0.30–1.86 µg/L), sediment (0.24–1.95 µg/kg), and ten congeners in fish tissues (0.25–0.70 µg/kg). Heptachlor, BHC isomers, DDT metabolites, endrin aldehyde, and aldrin/dieldrin dominated the contamination profile. OCP levels in water exceeded WHO/FEPA permissible limits for aldrin/dieldrin, endosulfan, ddt, and heptachlor while concentrations of fish were generally within FAO/WHO limits except for aldrin/dieldrin. Seasonal variations were significant in water and sediment ($p < 0.05$) but not in fish tissues ($p > 0.05$). Overall contamination followed the trend: sediment > water > fish, indicating sediments as major contaminant sinks. Non-carcinogenic and carcinogenic hazard indices for fish consumption were far below acceptable thresholds in both seasons, suggesting negligible health risks. However, elevated aldrin/dieldrin levels underscore the need for continuous monitoring, improved pesticide management, and public awareness to prevent future contamination and safeguard the ecosystem and public health.

Keywords: Fish, Hazard, Organic, Pollution, Sediment, Water

Introduction

Pesticides are synthetic substances which kill or suppress the activities of pests. One category of pesticides is organochlorine pesticides (OCPs), which are toxic, persistent, bioaccumulative and have

potential for long-range atmospheric transport (Kumar *et al.*, 2012). Other characteristics of pesticides, which include high lipophilicity and long half-life, have increased the chances of air, water, and

soil contamination for extended periods. Rapid population growth has driven the use of agrochemicals to improve agricultural production and meet high food demand. However, agrochemicals such as OCPs have caused several deleterious health and ecological effects. Likewise, an exponential increase in urbanization and industrialization has led to the immense release of these chemicals into the environment (Ezemonye *et al.*, 2015).

The aquatic environment often serves as a sink for many potentially harmful organic pollutants emitted from industrial and domestic sources, and contamination of water bodies by pesticide residues has been an issue of serious concern due to the health risks associated with them (Golfinopoulos *et al.*, 2003; Adeyemi *et al.*, 2011). These contaminants can enter water either through point sources like sewage plants, sewer overflows and poor management practices of farmers or through diffuse sources such as atmospheric deposition, runoffs and leaching from agricultural applications (Mayon *et al.*, 2006; Shukla *et al.*, 2006).

Quite a number of OCPs have been characterized and classified by the United States Environmental Protection Agency (USEPA), based on their toxicity as priority environmental pollutants. Measuring OCPs in biological samples is important due to their lipophilicity, which makes them to persist in the environment and accumulate in the aquatic biota, causing deleterious effects on the aquatic ecosystem (USEPA, 2007). The environmental persistence and toxicity of OCPs have led to their ban in many countries and are on the priority list of the European Community. However, they are still constantly in use in some developing countries, particularly in Nigeria. Following the uptake of these pollutants by fish, they tend to accumulate in the fatty tissue of fish because of their high chemical stability and lipophilic nature (USEPA, 2007). Fish can absorb these pesticides directly from water or by ingesting contaminated food (Teklit, 2016; Tongo *et al.*, 2014) and could pose potential human health hazards when consumed (Fianko *et al.*, 2011). A major pathway of human exposure to these contaminants has been identified primarily to be through food consumption (Edjerea *et al.*, 2020). Eating food contaminated with these chemicals may result in serious health implications (Wenaty *et al.*, 2019). Fish serves as an essential source of protein, minerals, and vitamins. It is highly sought after as an alternative to meat, and is a major constituent of most local diet in the coastal communities (Kafilzadeh *et al.*, 2012). Coastal populations are at the highest risk of dietary OCPs

exposure because they tend to consume relatively larger quantities of fish (Wenaty *et al.*, 2019).

Different levels of organochlorine residues and their possible health risks have been reported in fish (Ezemonye *et al.*, 2015; Fianko *et al.*, 2011), with different fish species varying greatly. However, despite the potential environmental/health hazard and the government efforts and legal instruments in place, activities involving the use of banned persistent organic pollutants (POPs), which are toxic substances that can remain in the environment for a long time, resist natural degradation, and can accumulate in living organisms, especially the OCPs, continue in the country (Alani *et al.*, 2022). POPs constitute a significant global ecological concern owing to their persistence, toxicity, bioaccumulation, and potential for health risks. Consequently, comprehensive assessment and continued monitoring of OCPs in our coastal waters are essential to assess environmental persistence and potential risks to aquatic ecosystems and human health. Hence, this study aims to evaluate the concentration of OCPs in surface water, sediment and *Chrysichthys nigrodigitatus* (Silver catfish) found in the Coastal creeks of Ondo State and its potential public health risk.

Materials and Methods

Study area

The coastal zone of Ondo State is located between Latitudes 5°50'N–6°09'N and Longitudes 4°45'E–5°05'E (Ajibare, 2014). It is predominantly inhabited by the Ilaje people, who live in linear settlements along the shoreline and rely extensively on coastal waters for domestic, economic, and transportation needs. The region supports intense human activities, including oil exploration, artisanal and commercial fishing, agriculture, trading, and boat construction, with waterborne transport serving as the primary means of movement of people and goods. These activities, coupled with municipal waste inputs, contribute significantly to the pollution of coastal waters and underlying sediments.

The dominant vegetation is mangrove swamp, particularly the red mangrove *Rhizophora racemosa* and white mangrove *Avicennia* spp., which typify the brackish water ecosystem. A notable ecological concern is the progressive desiccation of approximately 10,000 hectares of freshwater swamp forest due to saline water intrusion (Olusola & Festus, 2015). The terrain consists of low-lying swamp flats around the estuary, gradually rising toward the north. Numerous perennial streams and rivers drain the area, connecting several settlements before

discharging into the Atlantic Ocean, facilitating continuous land-sea water exchange (Loto *et al.*, 2023). Additionally, the coastline is marked by extensive erosion gullies, and during the dry season, mud cracks commonly develop on exposed saturated soil sediments. Four sampling stations (Rewoye, Ojumole, Ikorigho and Odonla) were selected along the creek for the study as shown in Figure 1.

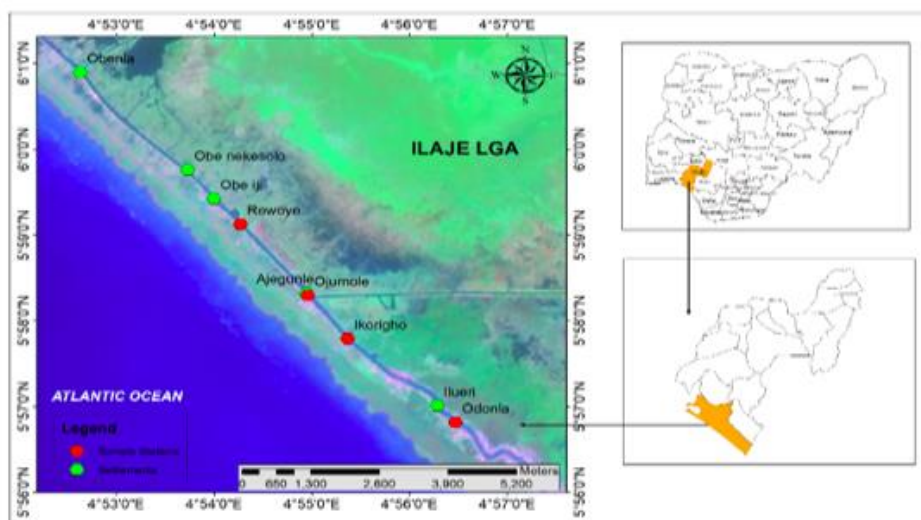


Figure 1: Map of the Coastal Creeks of Ondo State Showing the Study Sites

Collection of samples

Water sample: Two litres of water samples were collected monthly in triplicate from each study site between 07:00 and 11:00 hours, for two seasons (eight months), between February and September 2025. Sampling was done at the sub-surface using pre-acid-washed 2 L glass bottles to remove residual metals from manufacturing and dust particles. Each sample was acidified to pH < 2 with 2 mL of concentrated HNO₃ (APHA, 2000), transported to the Laboratory in an ice chest, and stored at 4°C until analysis.

Sediment sample: Five hundred grams (500g) of sediment samples were collected monthly from each sampling station for two seasons (eight months), between February and September 2025, using a Van Veen grab (0.5 cm²). The sediments were wrapped in foil, placed in an ice chest, transported to the Central Laboratory of the Nigerian Institute of Oceanography and Marine Research (NIOMR) in an ice chest, and stored at 4°C until analysis.

Fish sample: A commercially important fish species, silver catfish (*C. nigrodigitatus*), was used for this study. Thirty-two fish were collected monthly from each study area for two seasons (eight months), between February and September 2025. The fish were caught using a cast net from the coast. They were identified *in situ* according to Olaosebikan & Raji (2013) and transported to the Central Laboratory of NIOMR in an ice chest for necessary analysis.

Sample extraction and analysis

Organochlorine pesticides (OCPs) determination in water: Water samples were first filtered through 0.45 µm Whatman fiberglass filters to remove suspended particles. Extraction of OCP residues followed the method of USEPA (2002), as used by Kafizadeh *et al.* (2012). One hundred millilitres of filtered water were placed in a 1 L separating funnel and extracted with 50 mL of n-hexane. The mixture was vigorously shaken for 5 minutes and allowed to separate. The organic phase was collected, while the aqueous phase was re-extracted twice with fresh 50 mL portions of n-hexane. All organic extracts were combined and dried through a funnel packed with activated anhydrous sodium sulfate, then concentrated to near dryness using a rotary evaporator at 40°C.

For clean-up, 2.5 g of activated silica gel and 1 g of anhydrous sodium sulfate were packed into a glass column. The column was conditioned with n-hexane before transferring the extract, which was eluted with hexane-acetone mixtures. The eluates were concentrated to dryness, redissolved in 2 mL ethyl acetate, and transferred into GC vials. Analysis was carried out using an Agilent 7820A GC equipped with a 63Ni ECD and DB-17 capillary column. Instrument conditions, standards, blanks, and spiked samples were used to ensure proper calibration, peak identification, sensitivity, and recovery efficiency for all OCP compounds.

Determination of organochlorine pesticides (OCPs) in sediment: Sediment samples were air-dried and sieved through a 250 µm stainless-steel mesh.

Extraction of pesticide residues followed the method of USEPA (2002), as used by Kafilzadeh *et al.* (2012). Ten grams of dried sediment were placed in a pre-cleaned extraction thimble, and residues were extracted using 150 mL of n-hexane/acetone (1:1 v/v) in a Soxhlet apparatus for 6 hours. The extract was concentrated to near dryness with a rotary evaporator at 40°C, re-dissolved in 10 mL n-hexane, cleaned up, and transferred into vials for GC analysis. The clean-up was done according to the method of Shinggu *et al.* (2015). 2.5 g activated silica gel and 1 g anhydrous sodium sulfate were packed into a glass column and conditioned with n-hexane. The extract was loaded and eluted with portions of a hexane/acetone mixture. Eluates were concentrated to dryness, re-dissolved in 2 mL ethyl acetate, and transferred into GC vials. Analysis was carried out using an Agilent 7820A GC system fitted with a 63Ni ECD, split/splitless injector, capillary column, and autosampler. A DB-17 capillary column (30 m × 0.25 mm × 0.25 µm) was used under programmed temperature conditions. Nitrogen served as the carrier gas at 2 mL/min. Standards, blanks, and spiked samples were analyzed to verify column performance, detection limits, peak identification, and recovery accuracy for all pesticide compounds.

Organochlorine pesticides (OCPs) determination in fish: Fish samples were thawed, rinsed with distilled water, and descaled. Muscle tissues were dissected, chopped, and homogenized. Pesticide extraction followed the method of USEPA (2002), as used by Kafilzadeh *et al.* (2012). Ten grams of homogenized tissue were placed in a conical flask, mixed with 20 g of anhydrous sodium sulfate, and extracted with 30 mL of hexane/acetone (1:1 v/v). The mixture was sonicated for 20 minutes, and the supernatant was filtered into a round-bottom flask. Extraction was repeated twice, and the combined extracts were concentrated to near dryness at 40°C using a rotary evaporator. Each extract was dissolved in n-hexane, cleaned up, and prepared for GC analysis. Clean-up involved passing the extract through a glass column packed with 2.5 g activated silica gel and 1 g sodium sulfate, pre-rinsed with n-hexane. Elution was done with portions of hexane/acetone, after which the eluates were concentrated, redissolved in 2 mL ethyl acetate, and transferred to GC vials. Analysis was performed using an Agilent 7820A GC with 63Ni ECD and a DB-17 capillary column under programmed temperature conditions. Standards, blanks, and spiked samples were used to confirm column

performance, peak identity, detection limits, and recovery efficiency for all pesticide residues.

Human health risk assessment

Human health risk assessment was evaluated to know the likely undesirable health effects or risks associated with the consumption of fish contaminated with OCPs. This was done based on the standard of USEPA (1996). Assessment was carried out for adults (60kg) for both non-carcinogenic and carcinogenic health risks.

Estimated daily intake (EDI): The estimated daily intake (EDI) (mg/kg/day) of OCPs in fish samples were determined using Equation 1.

$$\text{Estimated Daily Intake (EDI)} = \frac{C_f \times \text{IFR}}{\text{BW}} \dots\dots\dots 1$$

Where: C_f = Conversion Factor; IFR = Food Ingestion Rate; BW = Average Body Weight.

Assessment of non-carcinogenic and carcinogenic health risks: Assessment of hazard quotient (HQ) of both non-carcinogenic and carcinogenic health risks as well as the hazard index (HI) were determined based on the standard of USEPA (1996), as described by Tongo *et al.* (2018).

$$\text{Hazard Quotient (HQ}_{\text{Non-carcinogenic}}) = \frac{\text{EDI}}{\text{RfD}} \dots\dots\dots 2$$

$$\text{Hazard Quotient (HQ}_{\text{Carcinogenic}}) = \text{EDI} \times \text{SF} \dots\dots\dots 3$$

Where: EDI = estimated daily intake; RfD = Oral Reference Dose; SF = Slope factor.

Guidelines for interpreting HQ calculations are:

HQ < 0.1 – no hazard exists

HQ = 0.1 – 1.0 – hazard is low

HQ = 1.1 – 10, hazard is moderate

HQ > 10, hazard is high

Hazard index: The hazard index, which estimates the total risk from multiple contaminant pathways, was obtained by summing the HQ of the contaminant pathways

$$\text{Hazard index HI} = \sum^n \text{HQ}_i \dots\dots\dots 4$$

Statistical analysis

The OCP concentrations in the water, sediment and fish tissues were subjected to Analysis of Variance (ANOVA) using IBM SPSS (version 22.0) to determine any significant difference, which was ascertained by Duncan's multiple range test. All statistical analyses were conducted at a significance level of 5% ($p < 0.05$).

Results**Concentrations of organochlorine pesticides in water**

The spatial concentrations of OCPs ranged from 0.30 to 1.86 µg/L across stations (Table 1). Heptachlor,

Delta-BHC, p,p'-DDD and Endrin Aldehyde showed the highest levels. Aldrin, Heptachlor epoxide, Endosulfan I, Endosulfan II and Methoxychlor were relatively low and similar across stations ($p>0.05$). The

Table 1: Mean $\pm$ SD spatial concentration of OCPs in surface water of the coastal creeks of Ondo State

OCPs (µg/L)	Sampling stations				WHO Guideline
	Rewoye	Ojumole	Ikorigho	Odonla	
Alpha-BHC	0.47 $\pm$ 0.09 ^{ab}	0.40 $\pm$ 0.08 ^{ab}	0.46 $\pm$ 0.09 ^{ab}	0.37 $\pm$ 0.09 ^a	NA
Beta-BHC	0.54 $\pm$ 0.09 ^b	0.47 $\pm$ 0.08 ^{ab}	0.54 $\pm$ 0.09 ^b	0.44 $\pm$ 0.09 ^a	NA
Heptachlor	1.86 $\pm$ 0.09 ^d	1.59 $\pm$ 0.26 ^{cg}	1.85 $\pm$ 0.09 ^d	1.41 $\pm$ 0.24 ^{bc}	0.03
Aldrin	0.78 $\pm$ 0.09 ^a	0.68 $\pm$ 0.08 ^a	0.77 $\pm$ 0.09 ^a	0.64 $\pm$ 0.09 ^a	0.03
Gamma-BHC	1.05 $\pm$ 0.09 ^b	0.93 $\pm$ 0.11 ^a	1.05 $\pm$ 0.09 ^b	0.86 $\pm$ 0.11 ^a	2.0
Delta-BHC	1.78 $\pm$ 0.09 ^c	1.52 $\pm$ 0.24 ^b	1.77 $\pm$ 0.09 ^c	1.35 $\pm$ 0.2 ^{ab}	NA
Heptachlor epoxide	0.51 $\pm$ 0.09 ^a	0.44 $\pm$ 0.08 ^a	0.51 $\pm$ 0.09 ^a	0.41 $\pm$ 0.09 ^a	0.03
Endosulfan I	0.38 $\pm$ 0.09 ^{ab}	0.32 $\pm$ 0.08 ^a	0.37 $\pm$ 0.09 ^{ab}	0.30 $\pm$ 0.09 ^a	NA
p,p' - DDE	0.86 $\pm$ 0.76 ^b	0.87 $\pm$ 0.70 ^b	0.60 $\pm$ 0.75 ^{ab}	0.65 $\pm$ 0.70 ^{ab}	NA
Dieldrin	0.81 $\pm$ 0.56 ^{ab}	0.78 $\pm$ 0.42 ^{ab}	1.08 $\pm$ 0.67 ^b	0.98 $\pm$ 0.57 ^{ab}	0.03
Endrin	0.39 $\pm$ 0.21 ^a	0.43 $\pm$ 0.16 ^{ab}	0.64 $\pm$ 0.48 ^{ab}	0.74 $\pm$ 0.53 ^c	0.6
p,p' - DDD	1.79 $\pm$ 0.15 ^c	1.61 $\pm$ 0.30 ^c	1.75 $\pm$ 0.21 ^c	1.61 $\pm$ 0.28 ^c	NA
Endosulfan II	0.74 $\pm$ 0.08 ^a	0.70 $\pm$ 0.11 ^a	0.73 $\pm$ 0.08 ^a	0.70 $\pm$ 0.10 ^a	NA
p,p' - DDT	1.01 $\pm$ 0.08 ^a	0.95 $\pm$ 0.14 ^a	1.00 $\pm$ 0.10 ^a	0.95 $\pm$ 0.12 ^a	1.0
Endrin Aldehyde	1.71 $\pm$ 0.14 ^b	1.54 $\pm$ 0.29 ^b	1.67 $\pm$ 0.20 ^b	1.54 $\pm$ 0.27 ^b	1.0
Endosulfan sulfate	0.48 $\pm$ 0.08 ^a	0.46 $\pm$ 0.10 ^a	0.48 $\pm$ 0.08 ^a	0.46 $\pm$ 0.09 ^a	NA
Methoxychlor	0.77 $\pm$ 0.53 ^a	0.58 $\pm$ 0.33 ^a	0.85 $\pm$ 0.61 ^a	0.74 $\pm$ 0.45 ^a	20
Total	0.94 $\pm$ 0.15	0.84 $\pm$ 0.21	0.95 $\pm$ 0.23	0.83 $\pm$ 0.24	

Mean ($n^{**}=8$) with the same superscript letter in a row are not significantly different ($p.0.05$) when subjected to Duncan multiple range test, DMRT (ANOVA post hoc); SD* = standard deviation; **n = number of observations (8 months)

Table 2: Spatial mean $\pm$ SD concentration of OCPs in bottom sediment from the coastal creeks of Ondo State

OCPs (µg/kg)	Sampling stations			
	Rewoye	Ojumole	Ikorigho	Odonla
Alpha-BHC	0.870.79 ^{ab}	1.03 $\pm$ 0.85 ^b	1.85 $\pm$ 0.41 ^c	1.80 $\pm$ 0.51 ^c
Beta-BHC	1.53 $\pm$ 0.70 ^b	1.55 $\pm$ 0.75 ^b	0.61 $\pm$ 0.46 ^a	0.59 $\pm$ 0.51 ^a
Heptachlor	1.06 $\pm$ 0.72 ^b	1.07 $\pm$ 0.80 ^b	1.95 $\pm$ 0.27 ^c	1.92 $\pm$ 0.34 ^c
Aldrin	1.58 $\pm$ 0.55 ^c	1.54 $\pm$ 0.54 ^c	1.00 $\pm$ 0.10 ^b	1.00 $\pm$ 0.18 ^b
Gamma-BHC	1.04 $\pm$ 0.11 ^b	1.03 $\pm$ 0.13 ^b	1.09 $\pm$ 0.09 ^b	1.06 $\pm$ 0.10 ^b
Delta-BHC	0.96 $\pm$ 0.31 ^{ab}	0.92 $\pm$ 0.37 ^{ab}	0.96 $\pm$ 0.23 ^{ab}	0.96 $\pm$ 0.29 ^{ab}
Heptachlor epoxide	0.76 $\pm$ 0.36 ^{bcd}	0.75 $\pm$ 0.38 ^{bcd}	0.33 $\pm$ 0.39 ^{ab}	0.28 $\pm$ 0.28 ^a
Endosulfan I	0.30 $\pm$ 0.28 ^a	0.47 $\pm$ 0.37 ^{ab}	0.65 $\pm$ 0.15 ^{abc}	0.62 $\pm$ 0.19 ^{abc}
p,p' - DDE	0.80 $\pm$ 0.51 ^b	0.67 $\pm$ 0.41 ^{ab}	0.39 $\pm$ 0.41 ^a	0.51 $\pm$ 0.42 ^{ab}
Dieldrin	0.62 $\pm$ 0.65 ^{ab}	0.30 $\pm$ 0.30 ^a	0.28 $\pm$ 0.30 ^a	0.59 $\pm$ 0.83 ^{ab}
Endrin	0.42 $\pm$ 0.41 ^a	0.56 $\pm$ 0.53 ^a	0.44 $\pm$ 0.38 ^a	0.24 $\pm$ 0.38 ^a
p,p' - DDD	0.47 $\pm$ 0.47 ^a	0.45 $\pm$ 0.51 ^a	1.24 $\pm$ 0.49 ^{bc}	1.24 $\pm$ 0.48 ^{bc}
Endosulfan II	1.14 $\pm$ 0.62 ^{bcd}	1.06 $\pm$ 0.57 ^{bc}	0.55 $\pm$ 0.55 ^a	0.77 $\pm$ 0.60 ^{ab}
p,p' - DDT	0.82 $\pm$ 0.45 ^{ab}	0.52 $\pm$ 0.38 ^a	0.77 $\pm$ 0.57 ^{ab}	1.01 $\pm$ 0.66 ^b
Endrin Aldehyde	0.90 $\pm$ 0.60 ^{ab}	1.18 $\pm$ 0.72 ^b	0.96 $\pm$ 0.68 ^{ab}	0.67 $\pm$ 0.34 ^a
Endosulfan sulfate	0.81 $\pm$ 0.65 ^b	0.58 $\pm$ 0.41 ^{ab}	0.56 $\pm$ 0.34 ^{ab}	0.92 $\pm$ 0.75 ^b
Methoxychlor	0.54 $\pm$ 0.33 ^a	0.55 $\pm$ 0.50 ^a	0.68 $\pm$ 0.43 ^a	0.69 $\pm$ 0.28 ^a
Total	14.62 $\pm$ 8.52	14.23 $\pm$ 8.52	14.31 $\pm$ 6.26	14.83 $\pm$ 6.95

Mean ($n^{**}=8$) with the same superscript letter in a row are not significantly different ($p.0.05$) when subjected to Duncan multiple range test, DMRT (ANOVA post hoc); SD* = standard deviation; **n = number of observations (8 months)

observed levels of Aldrin/Dieldrin, Endosulfan, DDT and Heptachlor were above the WHO/FEPA permissible limit for coastal water. During the dry season, higher concentrations of Beta-BHC, Heptachlor, Dieldrin, Endrin, p,p'-DDT, and p,p'-DDD were observed (Figure 2). In the wet season, higher concentrations of Alpha-BHC, Aldrin, Heptachlor epoxide, Endosulfan II, and Endosulfan were recorded (Figure 2). There were significant differences ($p < 0.05$) across the seasons.

Concentrations of organochlorine pesticides in sediment from the coastal creeks of Ondo State

The concentration of OCPs in sediment ranged from 0.24 to 1.95 $\mu\text{g}/\text{kg}$ (Table 2). Highest values were observed for Heptachlor (1.95 $\mu\text{g}/\text{kg}$) at Ikorigho, Aldrin (1.58 $\mu\text{g}/\text{kg}$) at Rewoye and Endosulfan II (1.14 $\mu\text{g}/\text{kg}$) at Rewoye. During the dry season, higher concentrations of Heptachlor, Endrin aldehyde and Methoxychlor were observed (Figure 3), while in the wet season, higher concentrations of Gamma-BHC, Delta-BHC, DDT, DDD and Endosulfan II were recorded (Figure 3). There were significant differences ($p < 0.05$) in OCP concentrations across the sampling stations and seasons.

Concentrations of organochlorine pesticides in the tissue of *C. nigrodigitatus* obtained from the coastal creeks of Ondo State

The concentrations of OCPs in *C. nigrodigitatus* ranged between 0.25 and 0.70 $\mu\text{g}/\text{kg}$ (Table 3). The highest bioaccumulated compounds are Aldrin, Dieldrin and BHC isomers. Ojumole had the highest total OCP load (4.00 $\mu\text{g}/\text{kg}$), while the lowest was recorded at Odonla

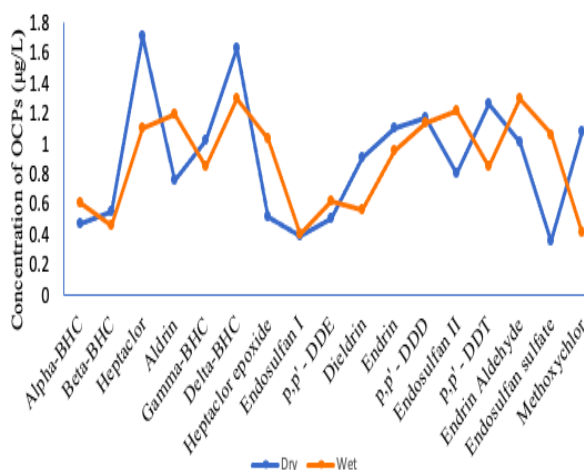


Figure 2: Seasonal variations of OCPs in surface water from the coastal creeks of Ondo State

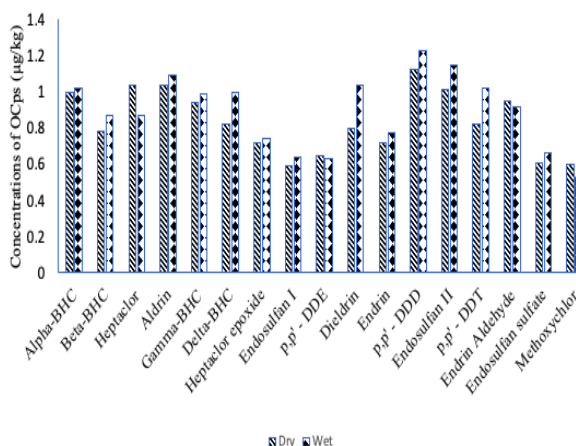


Figure 3: Seasonal variations of OCPs in sediment from the coastal creeks of Ondo State

Table 3: Spatial mean $\pm$ SD concentration of OCPs in *C. nigrodigitatus* from the coastal creeks of Ondo State

OCPs ($\mu\text{g}/\text{kg}$)	Sampling stations			
	Rewoye	Ojumole	Ikorigho	Odonla
Alpha-BHC	0.38 $\pm$ 0.39 ^a	0.34 $\pm$ 0.29 ^a	0.36 $\pm$ 0.23 ^a	0.33 $\pm$ 0.31 ^a
Beta-BHC	0.52 $\pm$ 0.38 ^a	0.54 $\pm$ 0.45 ^a	0.41 $\pm$ 0.36 ^a	0.35 $\pm$ 0.38 ^a
Heptachlor	0.38 $\pm$ 0.39 ^a	0.53 $\pm$ 0.50 ^a	0.47 $\pm$ 0.40 ^a	0.27 $\pm$ 0.38 ^a
Aldrin	0.65 $\pm$ 0.37 ^b	0.65 $\pm$ 0.39 ^b	0.68 $\pm$ 0.36 ^b	0.65 $\pm$ 0.46 ^b
Gamma-BHC	0.54 $\pm$ 0.40 ^a	0.44 $\pm$ 0.37 ^a	0.50 $\pm$ 0.25 ^a	0.70 $\pm$ 0.43 ^a
Delta-BHC	0.40 $\pm$ 0.33 ^a	0.48 $\pm$ 0.40 ^a	0.42 $\pm$ 0.37 ^a	0.24 $\pm$ 0.20 ^a
Endosulfan I	0.53 $\pm$ 0.47 ^a	0.50 $\pm$ 0.46 ^a	0.58 $\pm$ 0.54 ^a	0.57 $\pm$ 0.50 ^a
p,p' - DDE	0.32 $\pm$ 0.43 ^a	0.43 $\pm$ 0.42 ^a	0.40 $\pm$ 0.42 ^a	0.34 $\pm$ 0.37 ^a
Dieldrin	0.37 $\pm$ 0.41 ^a	0.55 $\pm$ 0.39 ^a	0.64 $\pm$ 0.44 ^a	0.57 $\pm$ 0.43 ^a
Methoxychlor	0.31 $\pm$ 0.25 ^{ab}	0.42 $\pm$ 0.32 ^{ab}	0.33 $\pm$ 0.33 ^{ab}	0.25 $\pm$ 0.21 ^a
Σ_{10} OCPs	3.70 $\pm$ 3.70	4.00 $\pm$ 4.00	3.71 $\pm$ 3.71	3.67 $\pm$ 3.67

Mean ($n^{**}=8$) with the same superscript letter in a row are not significantly different ($p < 0.05$) when subjected to Duncan multiple range test, DMRT (ANOVA post hoc); SD* = standard deviation; **n = number of observations (8 months)

Table 4: Non-Carcinogenic and Carcinogenic Hazard Quotient (HQ) of OCPs in *C. nigrodigitatus* from the coastal creeks of Ondo State

OCPs	Non carcinogenic		Carcinogenic	
	Wet season	Dry season	Wet season	Dry season
Heptachlor	3.67×10^{-9}	5.30×10^{-9}	2.57×10^{-3}	3.71×10^{-3}
Aldrin	1.22×10^{-8}	1.54×10^{-8}	6.91×10^{-3}	8.70×10^{-3}
Endosulfan I	1.38×10^{-6}	2.59×10^{-6}	NA	NA
p,p' - DDE	2.38×10^{-7}	1.68×10^{-7}	1.62×10^{-4}	1.14×10^{-4}
Dieldrin	7.77×10^{-9}	6.62×10^{-9}	2.49×10^{-3}	2.12×10^{-3}
Endrin	0.00	0.00	NA	NA
Methoxychlor	4.98×10^{-7}	9.95×10^{-7}	NA	NA
HI	2.18×10^{-6}	3.79×10^{-6}	1.64×10^{-2}	1.85×10^{-2}

NA: Not available; HI = Hazard Index; p,p' – DDE = DDE; OCPs = Organochlorine Pesticides

($3.67 \mu\text{g/kg}$). All the values were within the FAO/WHO permissible standard in fish, except for Aldrin/Dieldrin ($0.36\text{--}0.68 \mu\text{g/kg}$), which were higher than the $0.2 \mu\text{g/kg}$ OCP limit. OCP concentrations showed seasonal variation, with Aldrin highest in the dry season and Dieldrin highest during the wet season (Figure 4). The figure further revealed noticeable seasonal differences in pesticide residues ($\mu\text{g/kg}$) relative to the FAO/WHO standard. During the dry season, higher concentrations of Beta-BHC and DDE were observed. During the wet season, higher concentrations of Alpha-BHC, Heptachlor, Endosulfan I, and Dieldrin were recorded. There was no significant difference ($p>0.05$) in the OCP concentrations across the stations and seasons. The concentration of OCPs varied as follows: Sediment > Water > Fish.

Health risk assessment of OCPs in fish from the coastal creeks of Ondo State

Non-Carcinogenic Hazard Quotient (HQ) of OCPs in *C. nigrodigitatus* from the coastal creeks of Ondo State. The non-carcinogenic hazard quotient (HQ) values for organochlorine pesticides (OCPs) detected in *C. nigrodigitatus* from the coastal creeks of Ondo State are presented in Table 4. During the dry season, HQ values ranged from 0.00 to 2.59×10^{-6} , with a cumulative hazard index (HI) of 3.79×10^{-6} . In the wet season, HQ values ranged from 0.00 to 1.38×10^{-6} , corresponding to an HI of 2.18×10^{-6} .

Carcinogenic Hazard Quotient (HQ) of OCPs in *C. nigrodigitatus* from the coastal creeks of Ondo State. The carcinogenic hazard quotient (HQ) values for OCPs in *C. nigrodigitatus* from the coastal creek environment are summarised in Table 4. During the dry season, carcinogenic HQ values ranged from 1.14×10^{-4} to 8.70×10^{-3} , with a corresponding Hazard

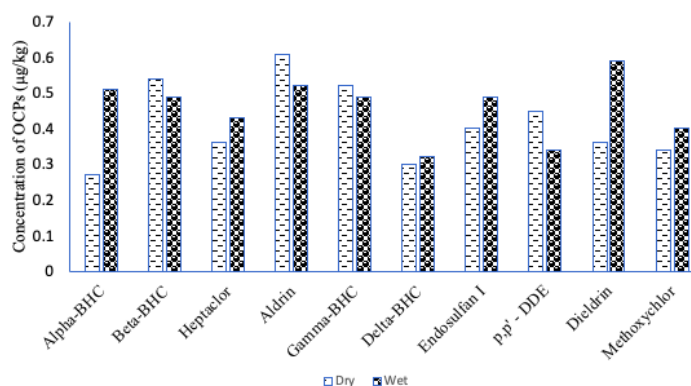


Figure 4: Seasonal variations in OCPs concentrations in *C. nigrodigitatus* from the coastal creeks of Ondo State

Index (HI) of 1.85×10^{-2} . In the wet season, HQ values ranged from 1.62×10^{-4} to 6.91×10^{-3} , yielding an HI of 1.64×10^{-2} . As with the non-carcinogenic assessment, all carcinogenic HQ and HI values were far below the acceptable limit.

Discussion

Organochlorine pesticides (OCPs) such as BHC isomers, aldrin, dieldrin, endosulfan, heptachlor, DDT and its metabolites are known for their environmental persistence, hydrophobicity and strong bioaccumulation potential in aquatic ecosystems. In the present study, surface water concentrations in the coastal creeks of Ondo State exceeded levels previously reported for Lagos Lagoon ($0.02\text{--}0.70 \mu\text{g/L}$), by Ezemonye *et al.* (2015), suggesting substantial contaminant inputs likely associated with agricultural discharge and catchment activities. These concentrations are consistent with observations from the selected rivers in four States (Lagos, Oyo, Ogun and Ondo) in South-West Nigeria, where Nuntah *et al.* (2020) attributed elevated OCP levels to agricultural runoff and oil-related disturbances. Seasonal patterns indicated higher dry-season concentrations for several compounds, which

may reflect reduced dilution, lower water volume and sediment resuspension. Conversely, wet-season increases in compounds such as aldrin and α -BHC suggest enhanced surface runoff from surrounding farmlands. Similar seasonal dynamics have been documented by Unyimadu *et al.* (2019) and Omoruyi *et al.* (2020) in comparable tropical coastal systems. Sediment exhibited notably higher OCP concentrations than water, consistent with the hydrophobic partitioning behaviour of these compounds. The presence of DDT metabolites (DDE and DDD) confirms historical DDT use and ongoing degradation. Elevated sediment concentrations observed in Ikorigho and Odonla may reflect higher sediment organic content, agricultural proximity and hydrodynamic trapping in creek bends. These findings align with studies by Alani *et al.* (2022), although they differ from Aminu & Adenuga (2024), who reported markedly higher values of OCPs in Ogun River sediments. The sediment contamination observed here highlights long-term persistence and the potential for future remobilisation into the water column.

OCP's concentrations in *C. nigrodigitatus* were lower than those in water and sediment, indicating moderate bioaccumulation. Although most residues remained within permissible limits, aldrin and dieldrin levels exceeded WHO guideline values, raising concerns regarding endocrine disruption, neurotoxicity and carcinogenicity. These concentrations are comparable to those reported in *Tilapia zilli* from Ogun River by Ogbeide *et al.* (2016) and in freshwater fish studied by Afolabi & Adekunle (2022). Seasonal trends showed increased wet-season bioavailability, while dry-season dominance of p,p'-DDE suggests enhanced DDT degradation under warmer conditions, in agreement with Ogbeide *et al.* (2016) and Unyimadu *et al.* (2019). Generally, the distribution trend (sediment > water > fish) reflects classical OCP partitioning behaviour.

Risk assessment results showed that non-carcinogenic HQ values were far below the threshold of 1 ($HQ < 1$), suggesting no anticipated non-cancer health effects from fish consumption. This agrees with Akpan *et al.* (2025), who reported similarly low HQs in commercial fish from Qua Iboe River, Nigeria. Carcinogenic HI values (0.016–0.019) were below 1, suggesting low, though not entirely negligible, lifetime cancer risk, comparable to values reported in farmed *Mugil cephalus* and *Oreochromis niloticus* in Egypt (Hussein *et al.*, 2022). Thus, although current risk levels are low, continued monitoring remains necessary due to the persistent nature of OCPs.

This study demonstrates the persistence, spatial and seasonal variation of OCPs in coastal creeks of Ondo State, with sediments serving as major contaminant sinks. While fish bioaccumulation was moderate and overall health risks remain low, exceedances for aldrin and dieldrin highlight the need for sustained monitoring and improved pesticide management practices, alongside community awareness programmes and ecological remediation strategies to limit future contamination and protect public health.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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