Determination of Pesticide Residues in the African Freshwater Prawn (*Macrobrachium vollenhovenii*) from Oba Market, Benin City, Edo State, Nigeria

BY

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FACULTY OF LIFE SCIENCES

UNIVERSITY OF BENIN

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE IN ANIMAL AND ENVIRONMENTAL BIOLOGY (BSCAEB)

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CERTIFICATION

This is to certify that this project was carried out by Samuel Abiona Oluwajoba of the Department of Animal and Environmental Biology, Faculty of Life Sciences, University of Benin, Benin City.

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PROF. MRS. I. TONGO DATE

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(Head of Department)

DEDICATION

This work is dedicated to God almighty and my entire family.

ACKNOWLEDGEMENT

I sincerely appreciate my parents, Mr. and Mrs. Abiona, for their endless love, prayers, and financial support throughout my academic pursuit. Their encouragement has been the foundation of my success.

My profound gratitude goes to my project supervisor, Professor Tongo Isioma, for her guidance, patience, and invaluable contributions to the completion of this research work. I also thank all the lecturers and staff of the Department of Animal and Environmental Biology, University of Benin, for their dedication and support.

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ABSTRACT

The accumulation of pesticide residues in aquatic organisms poses increasing concerns for environmental quality and food safety, particularly in regions characterized by intensive farming and inadequate waste management. This study investigated the concentrations of organochlorine pesticides (OCPs) and organophosphate pesticides (OPPs) in the African freshwater prawn (*Macrobrachium vollenhovenii*) obtained from Oba Market, Benin City, Edo State, Nigeria, with the objective of identifying possible contamination sources and assessing related human health risks. Prawn samples were analyzed using Gas Chromatography–Mass Spectrometry (GC–MS) for precise quantification of pesticide residues. Results indicated that total OCP concentrations ranged from 27.15 to 29.69 ppb, while total OPP levels varied between 6.98 and 10.99 ppb. When compared with the FAO/WHO Codex and European Union maximum residue limit (MRL) of 0.01 mg/kg for seafood, the mean residue levels were within permissible limits, suggesting minimal contamination. The estimated daily intake (EDI), based on an average prawn consumption rate of 0.33 kg/day for a 60 kg adult, remained below the acceptable daily intake (ADI), implying low immediate health risk. Similarly, the calculated hazard quotient (HQ) and hazard index (HI) values for both carcinogenic and non-carcinogenic effects were below 1, indicating no significant health threat at current exposure levels. However, the detection of banned or restricted compounds such as DDT and lindane (γ-HCH) underscores ongoing environmental contamination and potential bioaccumulation risks. The findings emphasize the need for continuous monitoring of pesticide residues in aquatic foods, stricter environmental regulations, and enhanced public education to mitigate long-term exposure and safeguard public health in Benin City and similar regions.

CHAPTER ONE

INTRODUCTION

Pesticides are widely used in modern agricultural practices to prevent pest infestation and improve crop productivity (Muyesaier Tudi *et al.,* 2021). Despite their agricultural benefits, the unregulated and excessive use of these chemicals has led to significant environmental pollution, particularly within aquatic environments (Riaz *et al.*, 2022). Pesticide residues often reach water bodies through pathways such as surface runoff, soil leaching, atmospheric drift, and improper disposal of agrochemicals (Riaz *et al.*, 2022; Stehle and Schulz, 2015). Once in the aquatic ecosystem, these residues can persist for long periods, accumulate in sediments and organisms, and pose ecological and human health challenges due to their toxicity, bioaccumulation, and ability to biomagnify along the food chain.

Among aquatic fauna, the African freshwater prawn (*Macrobrachium vollenhovenii*) is of considerable ecological and economic importance. It contributes significantly to food security and livelihoods in many Nigerian communities by serving as a high-protein dietary source and an income-generating resource (Falfushynska *et al.*, 2022; Zhang *et al.*, 2020). However, prawns are particularly vulnerable to aquatic pollutants because of their benthic feeding habits and constant interaction with contaminated sediments and water (Riaz *et al.*, 2022). Prawns are typically harvested from surrounding freshwater systems, which may receive agricultural runoff carrying pesticide residues from nearby farmlands (Jayakumar *et al.*, 2018). Over time, such exposures can lead to the accumulation of persistent pesticide residues in prawn tissues. Consequently, prawns can serve as sentinel species for monitoring aquatic pollution and assessing potential health hazards linked to seafood consumption.

Continuous evaluation of pesticide contamination in edible aquatic organisms is therefore critical for understanding the extent of environmental degradation, ensuring food safety, and protecting public health. Such assessments also provide valuable baseline data for regulatory authorities to strengthen environmental and food monitoring frameworks in Nigeria (Tudi *et al.*, 2021).

This study was carried out to determine the concentrations of organochlorine and organophosphate pesticide residues in the African freshwater prawn (*Macrobrachium vollenhovenii*) collected from Oba Market, Benin City, Edo State. The detected levels were compared with international safety standards to evaluate potential contamination sources and associated health risks for local consumers.

1.1 Aim and Objectives of the Study

This study aimed to assess the concentration levels of organochlorine and organophosphate pesticide residues in *Macrobrachium vollenhovenii* obtained from Oba Market, Benin City, Edo State, Nigeria, and to compare these levels with global food safety standards to evaluate potential human health implications.

The specific objectives of this study were to:

1. qantify the concentrations of organochlorine and organophosphate pesticide residues in *Macrobrachium vollenhovenii* from Oba Market, Benin City, Edo State.
2. compare the obtained pesticide concentrations with established international regulatory standards such as the FAO/WHO Codex Alimentarius and the European Union Maximum Residue Limits (MRLs).
3. evaluate the potential non-carcinogenic and carcinogenic health risks associated with the consumption of pesticide-contaminated prawns.

CHAPTER TWO

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

The use of pesticides dates back to the origins of agriculture, when early farmers sought ways to protect crops from pests. However, the modern era of pesticide application in agriculture and public health emerged in the 19th century, targeting pests such as mosquitoes, blackflies, fungi, and bacteria. Early control measures relied on toxic substances such as hydrogen cyanide, arsenic, and other hazardous compounds, which were eventually abandoned due to their high toxicity and limited effectiveness.

In Africa, the widespread use of pesticides in agriculture, public health, and domestic settings reflects their effectiveness in controlling insects, fungi, and disease vectors. However, these are inherently toxic compounds designed to harm, and when improperly handled, they pose serious risks to human health and ecosystems.

In 1873, the German chemist Othmar Zeidler first synthesized dichlorodiphenyltrichloroethane (DDT), although its insecticidal properties were not discovered until 1939 by the Swiss chemist Paul Hermann Müller. Following this discovery, DDT gained rapid global adoption due to its affordability, persistence, and remarkable effectiveness in controlling agricultural pests and disease vectors. Beyond agriculture, it was extensively used in public health programs for controlling malaria, typhus, and other vector-borne diseases (Zacharia, 2011).

Over the past century, organochlorine and organophosphate pesticides as well as several other trace organic pollutants have been extensively produced and released into the environment. Due to their persistence and mobility, these contaminants commonly enter aquatic systems via direct discharge, sediment transport, as well as hydrological and atmospheric pathways.

However, these chemicals, most times do not constitute a hazard to organisms in the forms which they are found in the environment. Once the organism has been exposed and the chemicals are readily bio-available, a series of biological interactions may occur. In view of the fact that their means of approach is by targeting the system or enzymes of pests; which are quite similar to the system or enzymes of humans, these organochlorine pesticides also pose threats to human health (Ghidini *et al.,* 2005; Bennet *et al.,* 1997).

In Nigeria and Africa at large, unprecedented population growth accompanied by an intense urbanization leading to increase in agricultural and industrial development (Biney *et al.,* 1987, 1994; Saad *et al.,* 1990) have caused a wide diversification in the types of pollutants that reach inland bodies of water giving rise to very undesirable effects and a major threat on prawns, other aquatic organisms and the entire aquatic environment.

Malaria, a major global infectious disease transmitted by mosquitoes, has necessitated the discovery and use of pesticides for public health. DDT has been continually used to reduce mosquito populations through indoor residual spraying in some developing countries. However, the repeated use of DDT has led to the development of resistance in mosquito populations, complicating control efforts (Schleier and Taglialatela-Scafati, 2009; Getachew, *et al.,* 2014). To manage resistance, strategies such as alternating insecticides, monitoring mosquito populations for resistance, and integrating biological control methods are recommended.

2.2 Organochlorine and Organophosphate Pesticides

Organochlorine (OC) and organophosphate (OP) pesticides are among the most persistent and toxic chemical classes affecting aquatic environments worldwide. These groups vary in their environmental behavior and human/ecological risk profiles, but both pose significant challenges to food safety and ecosystem health (Malhat *et al.*, 2018).

2.2.1 Organochlorine Pesticides (OCPs)

Organochlorines such as DDT, aldrin, dieldrin, lindane, and endosulfan are characterized by their high lipophilicity, resistance to degradation, and strong tendency to adsorb to soil and sediments. These traits lead to long-term persistence and bioaccumulation, enabling these chemicals to magnify through aquatic food chains and reach toxic concentrations in species like prawns and fish even decades after use has ceased (Unyimadu *et al.,* 2018). In Nigeria, several studies have found that OCs remain detectable in water, sediments, and aquatic organisms, with concentrations frequently exceeding regulatory thresholds suggesting ongoing ecological risks and possible illegal usage or legacy contamination. Toxicological concerns include endocrine disruption, reproductive failures, and potential carcinogenic effects in humans and wildlife.

2.2.2 Organophosphate Pesticides (OPPs)

In contrast, organophosphates such as chlorpyrifos, malathion, and dichlorvos are less persistent in the environment but exhibit high acute neurotoxicity. Their primary mechanism is the irreversible inhibition of acetylcholinesterase (AChE), causing an accumulation of acetylcholine at nerve synapses, which results in cholinergic overstimulation, neuromuscular paralysis, and potentially respiratory failure. Although OPs degrade more rapidly than OCs, their residues can still induce chronic effects in exposed organisms, including oxidative stress, immune suppression, and reproductive impairments if exposure is frequent (MDPI Toxicology Review, 2023).

2.2.3 Environmental Behavior and Risk Profile

OCPs pesticides persist for decades in sediments and remain biologically available to benthic organisms like prawns. Bioaccumulation and food-chain magnification make prawns particularly susceptible to residue accumulation over time. OPs, while less stable, enter aquatic ecosystems through agricultural runoff and improper disposal. Although they degrade faster, continuous or repeated use ensures chronic exposure risks.

2.3 Incidence of Organochlorine and Organophosphate in Prawns

Organochlorine (OC) and organophosphate (OP) pesticides are two major classes of synthetic chemicals widely used in agriculture, public health, and aquaculture to control pests. While effective, their persistence in the case of OCs and high acute toxicity in the case of OPs have raised significant ecological and public health concerns (Jayaraj *et al.,* 2016; UNEP, 2020). Prawns, being benthic and detritus-feeding crustaceans, are particularly vulnerable to pesticide contamination through direct exposure in water and indirect uptake from sediments and food sources. Due to their high lipid content and position in aquatic food chains, prawns can bioaccumulate pesticide residues, making them valuable bioindicators of aquatic pollution Lavariás and García, (2015). In many African countries, including Nigeria, studies have detected both OCs such as DDT, lindane, and dieldrin and OPs such as chlorpyrifos and fenitrothion in prawn tissues at varying levels Edwin *et al.,* (2021). Such contamination not only threatens prawn health and population stability but also poses potential risks to human consumers, particularly in communities where prawns form a regular part of the diet.

2.4 Effects of Pesticides on Prawns

Edwin *et al.,* (2021) evaluated the extent of organochlorine pesticide (OCP) contamination in *Macrobrachium vollenhovenii* and other commercially important finfish and shellfish from River Majidun, Lagos, Nigeria. The aim was to assess residue levels relative to national and international food safety standards and to identify possible public health risks. Muscle tissues were processed using Soxhlet extraction with organic solvents, and the extracts were analyzed for 16 target OCPs using gas chromatography equipped with an electron capture detector (GC-ECD). Several OCPs, including methoxychlor and γ-HCH (lindane), were detected in prawn samples, with concentrations ranging from approximately 0.01 to 0.87 mg/kg wet weight. While the majority of results fell below Codex Alimentarius maximum residue limits, certain samples exceeded Nigeria's Federal Ministry of Environment guideline values, suggesting localized contamination hotspots. They highlighted that bioaccumulation in prawns could pose a risk to frequent consumers, especially in communities relying heavily on riverine fisheries for protein.

A study by Galindo-Reyes, (2002) was carried out to investigate how sublethal exposure to organophosphorus pesticides affects respiration in *Litopenaeus vannamei* from a coastal lagoon in Sinaloa, Mexico. The aim was to determine whether common agricultural Ops such as diazinon, Folidol (parathion-methyl), and Gusathion (azinphos-methyl) could cause measurable physiological stress in shrimp. Adult specimens were collected from the lagoon, acclimated, and then exposed to each pesticide in aerated seawater under controlled laboratory conditions. Oxygen consumption was recorded using a polarographic electrode to assess metabolic activity. Results showed a marked, statistically significant decrease in respiration in all pesticide treatments compared to controls, with diazinon producing the largest reduction. These findings suggested that even low concentrations of OPs in coastal waters could impair shrimp metabolism, potentially affecting growth, health, and overall aquaculture yield.

Chávez *et al.,* (2012) study was undertaken to evaluate the extent of organochlorine (OCP) and organophosphorus (OP) pesticide contamination in shrimp-farming areas of Jiquilisco Bay, El Salvador, with the aim of determining possible risks to shrimp production and consumer safety. The research targeted farms located in an area influenced by nearby agricultural activities where pesticide runoff was suspected. Sampling was conducted in both the dry season (January–March) and rainy season (June–August) to identify seasonal variations in contamination. Water, soil, sediment, and shrimp (*Penaeus* sp.) samples were collected from multiple aquaculture sites. Analyses were performed using gas chromatography with an electron capture detector for OCPs and a flame photometric detector for OPs. Several OCPs including γ-HCH, p,p′-DDT, p,p′-DDE, p,p′-DDD, endrin, and dieldrin were detected in soils and deeper sediment layers, in some cases indicating historical use and persistence in the environment. However, none of these compounds, nor any OP pesticides, were detected in shrimp tissue, surface water, or surface sediments at the time of the study. It was concluded that while there is evidence of residual OCP contamination in the shrimp farming environment, the absence of residues in shrimp muscle tissue suggests that current farming practices and water exchange rates may be preventing significant bioaccumulation. Nonetheless, they recommended continued monitoring, as environmental disturbances or changes in land use could remobilize contaminants into the aquatic food web.

A study by Zhang *et al.,* (2024) investigated organophosphorus pesticide (OPP) contamination in *Litopenaeus vannamei* aquaculture ponds over a three-month grow-out period in southeast China. The aim was to determine residue levels in shrimp and their culture environment, as well as identify possible contamination sources. Water, sediment, suspended matter, and shrimp muscle tissue were sampled at regular intervals and analysed using a validated gas chromatography method with flame photometric detection. ΣOPP concentrations in shrimp ranged from 227–261 ng/g wet weight, with dimethoate as the dominant compound, followed by chlorpyrifos and diazinon. Concentrations in pond water, sediment, and suspended matter were also moderate but persistent throughout the culture cycle. Source analysis using PCA–MLR revealed that commercial feed and influent water were the main contamination sources. Although residue levels were below international maximum residue limits, the continual presence of OPs indicated a chronic exposure risk for cultured shrimp and potential long-term implications for aquaculture sustainability.

A study by Lavariás and García, (2015) investigated the acute toxic effects of the organophosphate pesticide fenitrothion on the freshwater prawn *Palaemonetes argentinus*, aiming to identify sensitive biochemical biomarkers of contamination. The researchers first determined the 96-hour lethal concentration (LC_{50}) by exposing adult prawns to varying levels of fenitrothion under controlled laboratory conditions; they also measured cholinesterase (ChE) activity in hemolymph and muscle, and assessed oxidative stress responses such as superoxide dismutase (SOD), catalase (CAT), glutathione-S-transferase (GST), and lipid peroxidation (LPO) in the hepatopancreas. The 96-hour LC_{50} was found to be 1.12 µg/L, pointing to high acute sensitivity. Hemolymph ChE activity was significantly inhibited in exposed prawns, while muscle ChE remained unchanged. Antioxidant enzymes (SOD, CAT, GST) were significantly elevated relative to controls, indicating an oxidative stress response, whereas LPO levels remained unaffected. The authors concluded that *P.*

argentinus is exceptionally sensitive to organophosphate exposure and that hemolymph ChE along with hepatopancreatic antioxidant enzyme activities offer effective early-warning biomarkers for assessing organophosphate contamination in freshwater environments.

2.5 Health Risk from Consuming Contaminated Prawn

Prawns are a valuable source of high-quality protein, essential fatty acids, vitamins, and minerals, making them an important component of the human diet in many coastal and inland communities (Abdel-Salam *et al.,* 2013). However, their nutritional benefits can be compromised by contamination with persistent and toxic pesticides such as organochlorines (OCPs) and organophosphates (OPs). These pesticides, introduced into aquatic systems through agricultural runoff, industrial discharge, and improper waste disposal, can bind to suspended particles or sediments, where prawn are exposed through ingestion and direct contact (Islam *et al.,* 2017). Because prawns occupy a relatively high position in the aquatic food web, they can bioaccumulate these compounds in their tissues, leading to elevated residue levels over time. OCPs, including DDT, dieldrin, and heptachlor, are lipophilic and highly resistant to degradation, meaning they persist for years and concentrate in prawn muscle and hepatopancreas. Chronic dietary exposure to such residues has been associated with endocrine disruption, reproductive impairments, and increased cancer risk in humans (ATSDR, 2002; WHO, 2020). OPs such as chlorpyrifos and malathion, though less persistent, are acutely neurotoxic because they inhibit acetylcholinesterase activity, and repeated low-level ingestion through seafood has been linked to developmental neurotoxicity and cognitive deficits, particularly in children (Falfushynska *et al.,* 2022; US EPA, 2021).

Several studies have detected pesticide residues in prawns above recommended safety thresholds. For instance, heptachlor residues in Bangladeshi prawn samples exceeded European Union maximum residue limits, while OCPs such as DDT and dieldrin, though below legal limits, were still present at measurable levels, raising concerns about cumulative exposure (Islam *et al.,* 2017). In Nigeria, OCPs banned decades ago have been reported in water, sediments, and aquatic organisms, indicating continued environmental contamination and bioavailability. Regulatory authorities such as the U.S. Food and Drug Administration (FDA) and European Food Safety Authority (EFSA) set maximum residue limits (MRLs) to reduce health risks, typically expressed in mg of contaminant per kg of prawn tissue (wet weight). However, these standards may differ by country, and many developing nations still rely on outdated or less stringent limits. Given that both OCPs and OPs can pose long-term health risks even at low concentrations, continuous monitoring, public health advisories, and stricter enforcement of pesticide regulations are essential to protect consumers.

2.6 Regulatory Standards and Maximum Residue Limits (MRLs)

Maximum Residue Limits (MRLs) are essential regulatory tools established to ensure that pesticide residues in food and feed remain within levels considered safe for human consumption. An MRL represents the highest concentration of a pesticide legally allowed in a food product, usually expressed in milligrams per kilogram (mg/kg). These limits are determined through extensive toxicological evaluations and are based on good agricultural practices to prevent adverse health effects (FAO/WHO, 2022).

Globally, the establishment of MRLs is primarily coordinated by the Codex Alimentarius Commission (CAC), jointly administered by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). The Codex standards serve as international benchmarks that guide trade and national food safety regulations. In addition to Codex, other regulatory bodies such as the European Commission (EU) and the United States Environmental Protection Agency (EPA) have developed specific MRLs for different food commodities, including fish and crustaceans. These limits differ depending on the chemical nature, persistence, and toxicity of each pesticide (U.S. EPA, 2021).

In Nigeria, pesticide regulation and food safety enforcement are primarily overseen by the National Agency for Food and Drug Administration and Control (NAFDAC) and the Federal Ministry of Environment. Due to limited national data and regulatory capacity, the country often relies on international MRLs established by Codex and the European Union (Olisah *et al.,* 2019). Nevertheless, several studies have reported the occurrence of pesticide residues in aquatic environments exceeding these permissible limits.

Continuous monitoring of pesticide residues in edible aquatic organisms is therefore crucial to ensure food safety and environmental protection. Comparing measured concentrations with established MRLs helps in evaluating compliance with safety standards, identifying emerging pollution threats, and guiding policy decisions. Strengthening national monitoring frameworks and aligning local standards with international guidelines will enhance Nigeria’s capacity to regulate pesticide use effectively, protect public health, and maintain ecological sustainability.

CHAPTER THTREE

MATERIALS AND METHOD

3.1 Study Area

The samples were collected from Oba Market, located in Benin City, Edo State, Nigeria (Figure 3.1). Oba Market is a major commercial hub where aquatic products, including prawns, are sold. The market provides an ideal site for assessing pesticide residues in raw prawns due to the diverse sources of aquatic products brought in by various vendors.

3.2 Sample Collection and Preparation

The freshwater prawn species (*Macrobrachium vollenhovenii*) (Plate 3.1) were procured from seafood vendors at Oba Market, Benin City, Edo State, Nigeria. The collected samples were immediately placed in ice-packed containers to preserve their integrity during transportation to the laboratory. Upon arrival, the prawns were identified to species level using diagnostic morphological features as described in the FAO Species Identification Guide (Holthuis, 1980). Each specimen was first weighed whole, then carefully deshelled, reweighed, and the tissue weight recorded. The deshelled edible portions of the samples (Plate 3.2) were subsequently placed in clean, non-reactive bottles, packed with ice packs to maintain a low temperature during transit and transported to the laboratory for analysis. A total of twenty (20) organochlorine and thirteen (14) organophosphate pesticide residues were examined in the African freshwater prawn (*Macrobrachium vollenhovenii*) obtained from Oba Market, Benin City, Edo State.

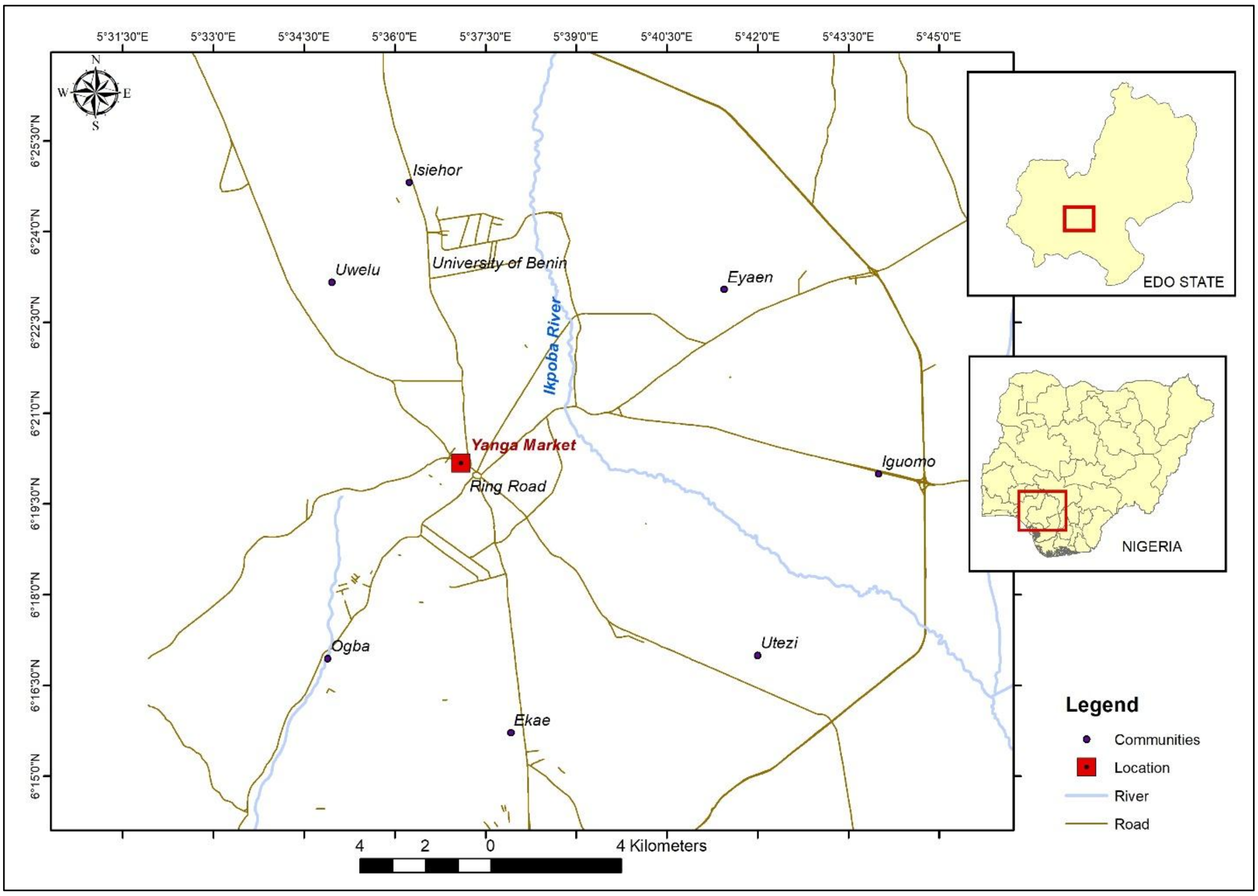

Figure 3.1: Map of Edo State showing Oba Market

Plate 3.1: Prawn species (*Macrobrachium vollenhovenii)* collected from Oba market, Benin City, Edo State.

Plate 3.2: Deshelled prawn samples (*Macrobrachium vollenhovenii)*

3.3 Pesticide Extraction, Cleanup and Analysis

Pesticide residues in the prawn samples were determined following the procedure described by USEPA (2007) with slight modifications. The analysis involved a multi-step process comprising extraction, clean-up, and instrumental detection using Gas Chromatography–Mass Spectrometry (GC–MS). Homogenised prawn tissues were weighed into clean glass beakers, after which 10 mL of a dichloromethane (DCM) and n-hexane mixture (1:3 v/v) was added as the extraction solvent. The mixtures were sonicated for 60 minutes at 70 °C to facilitate the release of pesticide residues from the tissue matrix. The extracts were allowed to stand for 24 hours to ensure complete solvent–sample interaction before filtration through Whatman No. 1 filter paper.

The filtrates were subjected to a clean-up step using a glass chromatographic column packed with activated silica gel. Elution was performed with n-hexane, and the eluates were concentrated to approximately 1 mL under a gentle stream of nitrogen. The concentrated extracts were then transferred into 2 mL Teflon-lined screw-cap vials for instrumental analysis. GC-MS analysis was conducted using an Agilent 6890N gas chromatograph coupled with an Agilent 5973 mass selective detector. The GC oven temperature was programmed to start at 80 °C and subsequently ramped in two stages to 300 °C. Identification and quantification of pesticide residues were achieved by comparing the retention times and mass spectral data of the sample components with those of certified analytical standards. Twenty (20) organochlorine and thirteen (14) organophosphate pesticides were assessed in the prawn samples.

3.4 Quality Control

To ensure the reliability of results, all analyses were performed in triplicates. Procedural blanks, standard reference materials, and spiked samples were included to check for contamination, recovery rates, and accuracy. All glassware and equipment were thoroughly cleaned before use.

3.5 Assessment of human health risk

The human health risk assessment was conducted to evaluate the potential adverse effects associated with the consumption of *Macrobrachium vollenhovenii* contaminated with PAHs from Oba Market, Benin City. Human exposure was estimated using intake models developed by the United States Environmental Protection Agency (USEPA, 1996). The assessment considered adult consumers with an average body weight of 60 kg and included evaluations for both non-carcinogenic and carcinogenic risks. The parameters, equations, and values applied in the calculations are summarised in Table 3.1.

3.5.1 Estimated Daily Intake (EDI)

The Estimated Daily Intake (EDI) of pesticide residues in *M. vollenhovenii* was determined to estimate potential human exposure through consumption. The EDI (mg/kg/day) was calculated using Equation (1), which relates the mean concentration of pesticide residues in the prawn samples (Cp), the average daily ingestion rate of crustaceans (IFR), and the average adult body weight (BW).

$$\text{Estimated Daily Intake (EDI)} = \frac{\text{Cp X IFR}}{\text{BW}} \qquad \text{Equation 1}$$

Table 3.1: Parameters used for estimating exposure assessment through Prawn Consumption

Parameters	Unit	Value	Reference
Mean concentration of pesticides (Cp)	mg/kg-Fish/Prawn	Table 4.1 and 4.2	Table 4.1 and 4.2
Reference Dose (RfD)	mg/kg/day	USEPA (1993)	USEPA (1993)
Crustacean ingestion rate (IFR)	Kg/capita/day	0.33 (Crustaceans)	FAO (2014)
Exposure Duration (ED)	years	60	Qu *et al.,* (2015)
Exposure Frequency (EF)	Days/year	365	Qu *et al.,* (2015)
Adult body weight (BW)	kg	60	Tongo *et al.,* (2017)
Average life span (ATn)	days	25550	Papadakis *et al.,* (2015)
Oral Slope Factor (SF)	mg/kg/day	—	US EPA (2005)

3.5.2 Assessment of Non-Carcinogenic and Carcinogenic Health Risks

Health risk assessments were conducted to evaluate both non-carcinogenic and carcinogenic risks associated with the consumption of contaminated prawns. The non-carcinogenic risk was expressed as the Hazard Quotient (HQ), calculated as the ratio of EDI to the Reference Dose (RfD), as shown in Equation (2), while for carcinogenic risk was estimated using Equation 3.

Hazard Quotient (HQ Non-carcinogenic) = $\frac{\mathrm{EDI}}{\mathrm{RfD}}$ Equation 2

Hazard Quotient (HQ Carcinogenic) = $EDI\ X\ SF$ Equation 3

The cumulative non-carcinogenic and carcinogenic risks from multiple pesticide residues were expressed as the Hazard Index (HI), obtained by summing the individual HQ values for all detected contaminants, as shown in Equation (4). Values of HQ and HI of contaminants below one (1) are considered as safe (USEPA, 1986).

$\mathrm{HI} = \sum_{(i=1)}^{n} \mathrm{HQ}_i$ Equation 4

Data analysis

Data were statistically analysed using Excel (2010). Mean, standard deviation, standard error, minimum, and maximum values were used to represent pesticide concentration in the prawn tissues. One-way analysis of variance (ANOVA) was used to compare differences between the levels of the pesticide, while Student t-test was used to compare differences between the total means of organochlorine and organophosphate pesticides

CHAPTER FOUR

RESULTS

4.1 Pesticide Residues in the African Freshwater Prawn (*Macrobrachium vollenhovenii*) from Oba Market

The analysis of African river prawns (*Macrobrachium vollenhovenii*) from Oba Market, Benin City, revealed the presence of both organochlorine (OCP) and organophosphate (OP) pesticide residues. The concentrations varied across different compounds, but detectable levels of pesticides were observed in all samples.

4.2 Organochlorine Residues in the African Freshwater Prawn (*Macrobrachium vollenhovenii*) from Oba Market

The organochlorine pesticide residues detected included α-HCH, β-HCH, γ-HCH (lindane), heptachlor, δ-HCH, aldrin, heptachlor epoxide, gamma-chlordane, alpha-chlordane, endosulfan I, P,p'-DDE, dieldrin , endrin, P,P'-DDD, endsulfan II, P,P'-DDT, endrin aldehyde, endosulfan sulfate, methoxychlor, and endrin ketone (Table 4.1), with mean concentrations ranging from 0 to 5.14 ppb. The total mean concentration of OCPs was 28.42 µg/kg, indicating a significant level of contamination in the prawns. The highest mean concentration was recorded for P,p´-DDD (5.14 µg/kg), followed by Dieldrin (3.16 µg/kg) and Endrin Aldehyde (2.64 µg/kg). However, there was no significant difference ($p>0.05$) in concentration between the organochlorine pesticides. Compounds such as α-HCH, endrin, and endosulfan sulfate were not detected (Table 4.1).

Table 4.1: Mean concentration of Organochlorine Pesticides found in Prawn Samples (*Macrobrachium vollenhoveni*) from Oba Market

Target compounds	Mean±SD	SE	Percentage (%)	Min	Max
α-HCH	0 ± 0	0	0	0	0
β-HCH	0.805±1.14	0.805	2.83	0	1.61
γ-HCH (lindane)	1.355±0.93	0.655	4.77	0.7	2.01
heptachlor	0.725±1.03	0.725	2.55	0	1.45
δ-HCH	2.17±0.76	0.54	7.64	1.63	2.71
aldrin	0.15±0.21	0.15	0.53	0	0.3
Heptachlor Epoxide	0.855±1.21	0.855	3.008	0	1.71
Gamma- Chlordane	0.505±0.71	0.505	1.78	0	1.01
Alpha- Chlordane	0.93±1.32	0.93	3.27	0	1.86
Endosulfan I	1.63±1.29	0.91	5.74	0.72	2.54
P,p'-DDE	2.14±1.58	1.12	7.53	1.02	3.26
Dieldrin	3.16±2.18	1.54	11.12	1.62	4.7
Endrin	0±0	0	0	0	0
P,P'-DDD	5.135±0.13	0.095	18.07	5.04	5.23
Endsulfan II	1.77±1.22	0.86	6.23	0.91	2.63
P,P'-DDT	0.87±1.23	0.87	3.06	0	1.74
Endrin aldehyde	2.64±1.68	1.19	9.30	1.45	3.83
Endosulfan sulfate	0±0	0	0	0	0
Methoxychlor	1.235±1.56	1.105	4.35	0.13	2.34
Endrin ketone	2.345±3.32	2.345	8.25	0	4.69
Total	28.42				

4.3 Percentage Contribution of each Organochlorine Pesticide in Prawn Samples (*Macrobrachium vollenhoveni*) from Oba Market

The percentage contribution of each organochlorine pesticide (OCP) to the total mean concentration revealed clear differences in contamination patterns (Table 4.1). Among all detected residues, P,p'-DDD (18.07%), Dieldrin (11.12%), Endrin aldehyde (9.29%), Delta-BHC (7.64%), and P,p'-DDE (7.53%) made the most significant contributions (Table 4.1) Compounds such as Endrin ketone (8.25%), Endosulfan I (5.74%), and Endosulfan II (6.23%) also contributed notably to the total OCP burden. In addition, Aldrin (0.53%), Gamma-Chlordane (1.78%), and Beta-BHC (2.83%) accounted for relatively minor proportions. Alpha-HCH, Endrin, and Endosulfan sulfate were not detected in the samples (Table 4.1).

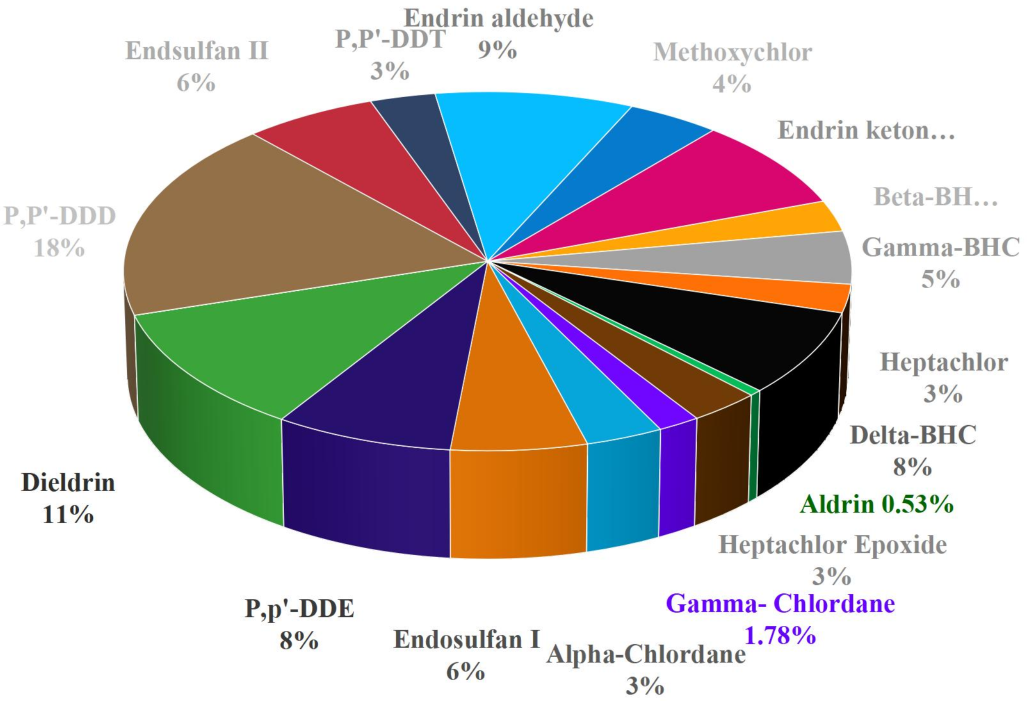

Figure 4.1: Percentage concentration of organochlorine pesticides in the African freshwater prawns (*Macrobrachium vollenhoveni)* from Oba market in Benin City.

4.4 Organophosphate Residues in the African Freshwater Prawn (*Macrobrachium vollenhovenii*) from Oba Market

The organophosphate pesticides detected included 1,3-dimethyl-2-nitrobenzene, diazinone, Isazophos, chlorpyriphos-methyl, pirimiphos methyl, fenitrthion, pirimiphos ethyl, quinalphos, chlorpyrifos, EPN, phosalone, pyrazophos, azinphos-ethyl and pyraclofos (Table 4.2). Their levels were generally lower compared to OCPs, with a total mean concentration of 8.98 µg/kg. Chlorpyriphos-methyl was the most abundant OP residues detected with mean value of 1.845 µg/kg. However, there was no significant difference ($p>0.05$) in concentration between the organophosphate pesticides. Diazinon, Pirimiphos Methyl, and Chlorpyrifos were not detected (Table 4.2).

Table 4.2: Mean concentration of Organophosphate Pesticides found in Prawn Samples (*Macrobrachium vollenhoveni*) from Oba Market

Target compounds	**Mean±SD**	**SE**	**Percentage (%)**	**Min**	**Max**
1,3-dimethyl-2-nitrobenzene	0.875±1.24	0.875	6.24	0	1.75
Diazinone	0±0	0	0	0	0
Isazophos	0.07±0.09	0.07	0.50	0	0.14
Chloropyriphos-methyl	1.845±1.49	1.055	13.16	0.79	2.9
Pirimiphos Methyl	0±0	0	0	0	0
Fenitrthion	1.43±0.59	0.42	10.19	1.01	1.85
Pirimiphos Ethyl	0.57±0.14	0.1	4.06	0.47	0.67
Quinalphos	0.89±0.23	0.16	6.35	0.73	1.05
Chlorpyrifos	0±0	0	0	0	0
EPN	0.46±0.65	0.46	3.28	0	0.92
Phosalone	1.52±0.09	0.06	10.84	1.46	1.58
Pyrazophos	0±0	0	0	0	0
Azinphos-ethyl	1.325±1.77	1.255	9.45	0.07	2.58
Pyraclofos	0±0	0	0	0	0
Total	8.985				

4.5 Percentage Contribution of Each Organophosphate Pesticide in Prawn Samples (*Macrobrachium vollenhoveni*) from Oba Market

The percentage contribution of organophosphate pesticides to the total mean concentration showed that Chloropyriphos-methyl (13.16%) was the most dominant contaminant (Table 4.2), accounting for close to one-third of the total OP burden. Other notable contributors included Phosalone (10.84%), Fenitrothion (10.20%), and Azinphos-ethyl (9.45%), each making significant contributions to the residue profile (Table 4.2). Minor but detectable contributions came from Quinalphos (6.35%), 1,3-dimethyl-2-nitrobenzene (6.24%), and Pirimiphos Ethyl (4.06%), while EPN (3.28%) and Isazophos (0.50%) were low. Some compounds, such as Diazinon, Pirimiphos Methyl, Chlorpyrifos, Pyrazophos, and Pyraclofos, were not detected in the samples (Table 4.2).

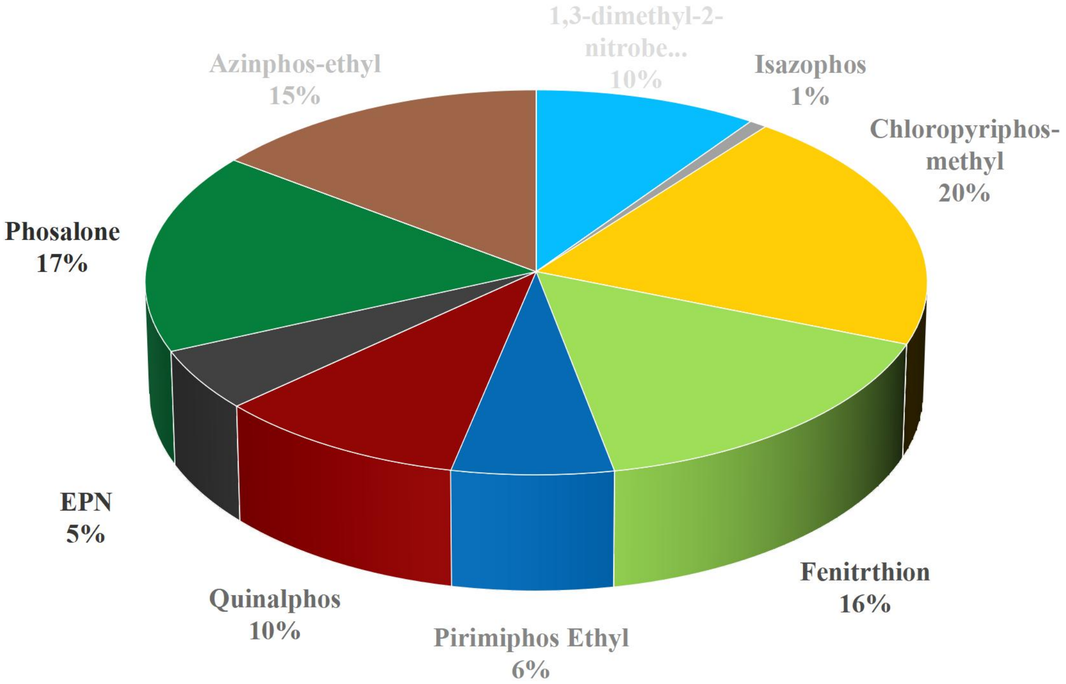

Figure 4.2: Percentage concentration of organophosphate pesticides in African freshwater prawns (*Macrobrachium vollenhoveni)* from Oba market in Benin City.

4.6 Comparative Analysis of OCPs and OPPs in Prawn Samples (*Macrobrachium vollenhoveni*) from Oba Market

When comparing the two pesticide groups, organochlorines (28.42 µg/kg) were dominant compared to the organophosphates (8.98 µg/kg) (Figure 4.3), with the OCPs significantly higher ($p < 0.05$) than the OPPs in the prawn tissues.

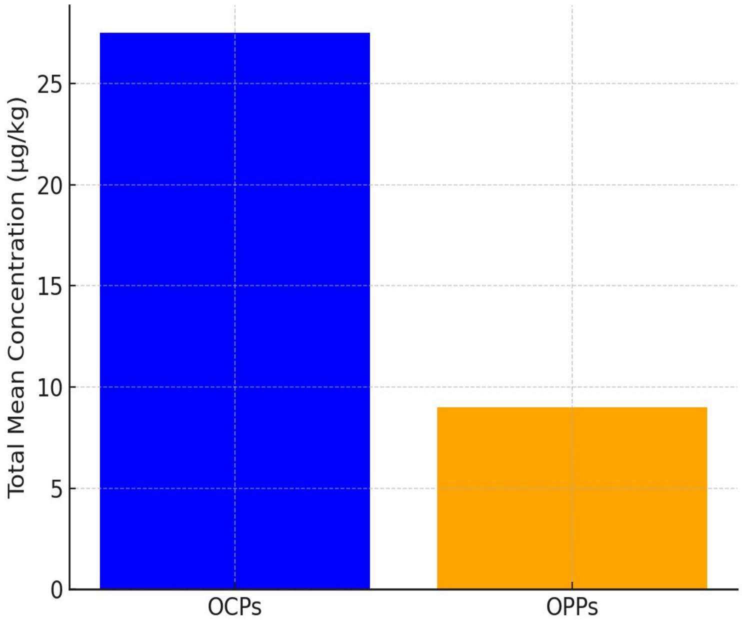

Figure 4.3: Comparative levels of total mean concentrations of OCPs and OPs in Prawn Samples (*Macrobrachium vollenhoveni*) from Oba Market

4.7 Human Health Risk Assessment of Pesticide Concentrations in the African freshwater prawn (*Macrobrachium vollenhoveni)*

The estimated daily intake (EDI), hazard quotients (HQs) and hazard index (His) of pesticide residues in the prawn tissues from Oba Market are presented in Tables 4.3 and 4.4.

EDI values for the OCPs ranged from 0.000000 to 0.000016 (Table 4.3). The hazard quotient (HQs) and hazard index (HIs) values for OCPs in prawn samples for the estimated non-carcinogenic and carcinogenic health risk were below 1 (Table 4.3).

EDI values for the OPPs ranged from 0 to 7.2875E-06 (Table 4.4). The hazard quotient (HQs) and hazard index (HIs) values for OPPs in prawn samples for the estimated non-carcinogenic and carcinogenic health risk were below 1 (Table 4.4).

Table 4.3: Estimated Daily Intake, hazard quotients (HQs) and hazard index (HIs) of OCPs in the prawn tissues from Oba Market

OCPs	MEAN(Cp)	IFR	BW	EDI	RfD	HQ(Noncarcinogenic)	SF	HQ(Carcinogenic)
α - HCH	0.000805	0.330000	60.000000	0.000004	0.008000	0.000553	6.300000	0.000028
β-HCH	0.000350	0.330000	60.000000	0.000002	NA	NA	NA	NA
γ - HCH (LINDANE)	0.001730	0.330000	60.000000	0.000010	0.000300	0.031717	1.300000	0.000012
Heptachlor	0.001355	0.330000	60.000000	0.000007	0.000500	0.014905	4.500000	0.000034
δ-HCH	0.000815	0.330000	60.000000	0.000004	NA	NA	NA	NA
Aldrin	0.001005	0.330000	60.000000	0.000006	0.000030	0.184250	17.000000	0.000094
Heptachlor Epoxide	0.000000	0.330000	60.000000	0.000000	0.000013	0.000000	9.100000	0.000000
Gamma-Chlordane	0.001435	0.330000	60.000000	0.000008	NA	NA	NA	NA
Alpha-Chlordane	0.000360	0.330000	60.000000	0.000002	NA	NA	NA	NA
Endosulfan I	0.002900	0.330000	60.000000	0.000016	0.006000	0.002658	NA	NA
P,p'-DDE	0.001320	0.330000	60.000000	0.000007	NA	NA	0.340000	0.000002
Dieldrin	0.002350	0.330000	60.000000	0.000013	0.000050	0.258500	16.000000	0.000207
Endrin	0.002615	0.330000	60.000000	0.000014	0.000300	0.047942	NA	NA
P,P'-DDD	0.002975	0.330000	60.000000	0.000016	NA	NA	0.240000	0.000004
Endsulfan II	0.002185	0.330000	60.000000	0.000012	0.006000	0.002003	NA	NA
P,P'-DDT	0.001915	0.330000	60.000000	0.000011	0.000500	0.021065	0.320000	0.000003
Endrin aldehyde	0.000725	0.330000	60.000000	0.000004	NA	NA	NA	NA
Endosulfan sulfate	0.001170	0.330000	60.000000	0.000006	NA	NA	NA	NA
Methoxychlor	0.000065	0.330000	60.000000	0.000000	0.005000	0.000072	NA	NA
Endrin ketone	0.002345	0.330000	60.000000	0.000013	NA	NA	NA	NA
					HI	**0.564**		**0.0004**

Key: NA= Not Available

RfD = Reference Dose

Table 4.4: Estimated Daily Intake,_hazard quotients (HQs) and hazard index (HIs) of OPPs in the prawn tissues from Oba Market.

OPPs	MEAN(Cp)	IFR	BW	EDI	RfD(ADI)	HQ(Non-carcinogenic)	SF	HQ(Carcinogen
1,3-dimethyl-2-nitrobe...	0.000875	0.33	60	4.8125E-06	0.0009	0.005347222	NA	NA
Diazinon	0	0.33	60	0	0.0009	0	NA	NA
Isazophos	0.00007	0.33	60	0.000000385	NA	NA	NA	NA
Chlorpyrifos-methyl	0.001845	0.33	60	1.01475E-05	0.01	0.00101475	NA	NA
Pirimiphos Methyl	0	0.33	60	0	NA	NA	NA	NA
Fenitrthion	0.00143	0.33	60	0.000007865	NA	NA	NA	NA
Pirimiphos Ethyl	0.00057	0.33	60	0.000003135	NA	NA	NA	NA
Quinalphos	0.00089	0.33	60	0.000004895	NA	NA	NA	NA
Chlorpyrifos	0	0.33	60	0	3E-03	NA	NA	NA
Ethyl paranitrophenyl phenylphosphonothioate (EPN)	0.00046	0.33	60	0.00000253	NA	NA	NA	NA
Phosalone	0.00152	0.33	60	0.00000836	NA	NA	NA	NA
Pyrazophos	0	0.33	60	0	NA	NA	NA	NA
Azinphos-ethyl	0.001325	0.33	60	7.2875E-06	NA	NA	NA	NA
Pyraclofos	0	0.33	60	0	NA	NA	NA	NA
					HI	**0.001**		

Key: NA= Not Available

RfD = Reference Dose

CHAPTER FIVE

DISCUSSION

The study investigated pesticide residues in African river prawns (*Macrobrachium vollenhovenii*) obtained from Oba Market, Benin City, focusing on organochlorine (OCP) and organophosphate (OPP) pesticides. The results revealed the presence of several OCP compounds with varying concentrations. Notably, P,p′-DDD, Dieldrin, and Endrin Aldehyde were the most abundant, accounting for more than one-third of the total residue burden. The detection of these compounds indicates that despite global and national restrictions on the use of organochlorines, residues persist in the environment due to their high stability, lipophilicity, and resistance to degradation. This persistence allows OCPs to bioaccumulate in aquatic organisms such as prawns, which are important both ecologically and economically as a food source (Jayaraj *et al.,* 2016).

These findings align with earlier studies in Nigerian aquatic systems which reported persistence of banned organochlorines, particularly DDT metabolites and cyclodiene compounds. The detection of P,p′-DDD and P,p′-DDE indicates environmental degradation products of DDT, suggesting historical or ongoing inputs of this banned pesticide. The high concentrations of dieldrin and endrin derivatives further highlight the persistence of these compounds in the aquatic environment. They are both highly lipophilic, bioaccumulative, and known for their long half-lives in sediments and tissues (Akinyemi *et al.,* 2019).

On the other hand, the organophosphate pesticide analysis showed residues of compounds with concentrations generally at lower levels compared to OCPs. This may be attributed to the fact that organophosphates have shorter environmental half-lives, and undergo faster degradation in the environment (less persistent) compared to organochlorines. However, their acute toxicity makes them particularly harmful in the short term, even at low concentrations. The detection of OPPs highlights ongoing and possibly recent agricultural applications, since these pesticides degrade relatively quickly but are still widely used in crop protection.

This aligns with earlier findings by Crentsil Kofi *et al.,* (2012), who reported that while organophosphates do not accumulate as heavily as organochlorines, their residues in aquatic organisms serve as indicators of current pesticide use in farming activities. Thus, the presence of organophosphates in the sampled prawns highlights the continuous reliance on these chemicals for pest control in surrounding agricultural landscapes, which poses potential risks to aquatic life and consumers.

When comparing both pesticide groups, a clear distinction emerges: OCPs, though banned or restricted, still persist in the aquatic ecosystem and bioaccumulate in prawns due to their lipophilic nature and resistance to degradation. OPPs, while less persistent, reflect current usage trends and pose acute toxicity risks due to their mechanism of inhibiting acetylcholinesterase. The co-occurrence of both classes of pesticides in prawns raises significant food safety and public health concerns, particularly for consumers in Benin City who may be exposed through dietary intake.

When compared to the FAO/WHO Codex and EU default maximum residue limit (MRL) of 0.01 mg/kg for seafood**,** the total mean pesticide residue for the OCPs (0.03 mg/kg) was above the threshold value (0.01 mg/kg), which calls for concern. The estimated daily intake (EDI) values obtained for all detected pesticides were however, below their respective acceptable daily intake (ADI) thresholds, indicating minimal potential for immediate adverse health effects. Similarly, the hazard quotient (HQ) and hazard index (HI) values were both less than one (<1), implying that prawn consumption at current residue levels is unlikely to cause significant non-carcinogenic or carcinogenic health effects. Nevertheless, continuous exposure to even low concentrations of pesticide residues could lead to chronic health implications over time, particularly among frequent seafood consumers or individuals with greater physiological vulnerability (Gama *et al.,* 2022).

5.1 Conclusion and Recommendations

The study assessed the levels of organochlorine and organophosphate pesticide residues in African river prawns (*Macrobrachium vollenhovenii*) obtained from Oba Market, Benin City. The results revealed the presence of varying concentrations of pesticide residues, with the total mean pesticide residue for the OCPs (0.03 mg/kg) exceeding the FAO/WHO Codex and EU default maximum residue limit (MRL) of 0.01 mg/kg, which calls for concern. This indicates that prawns sold in the market may constitute a potential health risk to consumers through bioaccumulation of toxic compounds. The persistence of organochlorines, coupled with the toxicity of organophosphates, shows the implications for both food safety and public health.

The detection of multiple pesticide residues indicates the possibility of long-term and combined exposure risks to both humans and aquatic organisms. To mitigate these risks, it is recommended that routine monitoring of pesticide residues in aquatic foods and adjacent water bodies be conducted. Regulatory agencies should strengthen the enforcement of pesticide control policies, encourage the adoption of sustainable pest management strategies such as Integrated Pest Management (IPM), and intensify public education on the safe use and disposal of pesticides. Furthermore, future research should examine seasonal fluctuations in pesticide concentrations, assess contamination within sediments, and investigate the potential for biomagnification across aquatic trophic levels. These measures will contribute to a more comprehensive understanding of pesticide impacts and promote better protection of ecosystem and human health.

REFERENCES

Abdel-Salam, H. A., Ali, S. M., and El-Aasr, M. S. (2013). Evaluation of nutritional quality of commercially cultured Indian white shrimp (*Penaeus indicus*). *International Journal of Nutrition and Food Sciences,* ***2***(4), 160–166.

Adekunle, O. O., Yusuf, O. M., and Hammed, A. K. (2022). Organophosphate pesticide residues impact on water quality and macroinvertebrate community in a tropical stream flowing through farmlands (Chanchaga River, Niger State, Nigeria). *Environment and Ecology Research,* ***10***(5), 262–273.

Akinyemi, I. G. (2019). *Safety of active ingredients in commonly used pesticides in Nasarawa State, Nigeria.* Journal of Forestry Research & Management, **16**(1), 57- 65.

Aktar, M. W., Sengupta, D., and Chowdhury, A. (2009). Impact of pesticide use in agriculture: Their benefits and hazards. *Interdisciplinary Toxicology,* ***2***(1), 1–12.

ATSDR. (2002). *Toxicological profile for DDT, DDE, and DDD.* Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services. https://www.atsdr.cdc.gov/ToxProfiles/tp35.html.

Betts, J. T., Mendoza Espinoza, J. F., Dans, A. J., Jordan, C. A., Mayer, J. L., and Urquhart, G. R. (2020). Fishing with pesticides affects river fisheries and community health in the Indio Maíz Biological Reserve, Nicaragua. *Sustainability,* ***12***(23), 10152.

Biney, C. A., Calamari, D., Naeve, H., Maembe, T. W., Nyakageni, B., and Saad, M. A. H. (1987). *Scientific bases for pollution control in African inland waters.* Chemistry and Ecology, **3**(1), 49-74.

Crentsil Kofi Bempah, Asomaning, J. and Boateng, J. (2012). *Market basket survey for some pesticide residues in fruits and vegetables from Ghana. Journal of Microbiology, Biotechnology and Food Sciences*, **2**(3), 850- 871

Edwin, O., Clarke, O. A., Akintade, P., Ndimele, E., and Olarinmoye, M. (2021). Assessment of persistent organochlorine pesticide residues in commercially important fin and shell fishes of River Majidun, Lagos, Nigeria. *Current Journal of Applied Science and Technology, **40***(1), 142–153.

Edwin, O. O., Clarke, E. O., Akintade, A. O., Ndimele, P. E., and Olarinmoye, O. M. (2021). Organochlorine pesticide residues in finfish and shellfish from River Majidun, Lagos, Nigeria. *Environmental Monitoring and Assessment, **193***(6), 337.

FAO/WHO. (2022). *Codex Alimentarius: Pesticide residues in food and feed.* https://www.fao.org/fao-who-codexalimentarius.

Falfushynska, H., Gnatyshyna, L., Osypenko, I., and Stoliar, O. (2022). Pesticide pollution: Detrimental outcomes and possible mechanisms of fish exposure to common organophosphates and triazines. *Ecotoxicology and Environmental Safety, **242**,* 113903.

Galindo- Reyes, R. J., Dalla- Venezia, L. and Lazcano Álvarez, A. M. (2002). *Effect of some organophosphorus pesticides on oxygen consumption of shrimp, Litopenaeus vannamei. Ecotoxicology and Environmental Safety*, **52**(2), 134- 136.

Gama, F., Neves, R. and Pereira, E. (2022). *Chronic effects of dietary pesticides on the gut microbiome and neurodevelopment.* Frontiers in Microbiology, **13**, 931440.

Getachew, D., Balkew, M., Tekie, H., Tushune, K., Olana, D., and Duchateau, L. (2014). Evaluation of the efficacy of DDT indoor residual spraying and long-lasting insecticidal nets against insecticide-resistant populations of *Anopheles arabiensis* Patton (Diptera: Culicidae) from Ethiopia using experimental huts. *Parasites and Vectors, 7*(1), 131.

Islam, M. A., Das, R., Rahman, M. M., Islam, H. M. R., Mahmud, Y., and Ahmed, K. K. U. (2017). Bioaccumulation of some organochlorine pesticide residues in shrimp/prawn of south-west Bangladesh and assessment of probable risk on human health. *International Journal of Science and Research,* ***6***(6), 1135–1143.

Jayakumar, R., Paul, V. I., and Kannan, S. (2018). Impact of agricultural runoff on water quality and aquatic organisms in prawn culture systems: A review. *International Journal of Fisheries and Aquatic Studies,* ***6***(2), 120–126.

Jayaraj, R., Megha, P., and Sreedev, P. (2016). Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment. *Interdisciplinary Toxicology,* ***9***(3–4), 90–100.

Khatib, I., Rychter, P., and Falfushynska, H. P. (2022). Pesticide pollution: Detrimental outcomes and possible mechanisms of fish exposure to common organophosphates and triazines. *Journal of Xenobiotics,* ***12***(3), 236–265.

Kumar, P., Malik, A., and Prasad, T. (2018). Migration of pesticide residues from recycled plastic packaging to food. *Food Control,* ***93****,* 29–35.

Lavariás, S., and García, C. F. (2015). Acute toxicity of the organophosphate fenitrothion on biomarkers in the prawn *Palaemonetes argentinus* (Crustacea: Palaemonidae). *Environmental Monitoring and Assessment, **187***(2), 59.

Malhat, F., Loutfy, N. M., Greish, S. S., and Ahmed, M. T. (2018). A review of environmental contamination by organochlorine and organophosphorus pesticides in Egypt. *Journal of Toxicology and Risk Assessment, **4***(1), Article 013.

Marioghae, I. E. (1987). *An appraisal of the cultivability of Nigerian palaemonid prawns (ARAC/87/WP/4).* Food and Agriculture Organization (FAO).

New, M. B. (2002). *Farming freshwater prawns: A manual for the culture of the giant river prawn (Macrobrachium rosenbergii).* FAO Fisheries Technical Paper 428. Food and Agriculture Organization of the United Nations.

Nwosu, F. M., and Wolfi, M. (2006). Population dynamics of the giant African river prawn *Macrobrachium vollenhovenii* Herklots, 1857, in the Cross River Estuary, Nigeria. *West African Journal of Applied Ecology, **9***(1), 1–18.

Odulate, D. O. (2023). Morphometric and meristic characterization of *Macrobrachium vollenhovenii* in Ogun River, Abeokuta, Nigeria. *Nigerian Journal of Fisheries, **12***(1), 1–10.

Okere, A. O., Smith, B., and Chukwu, I. (2024). Morphologic and phylogenetic investigations of *Macrobrachium vollenhovenii* across West African river basins. *Journal of Basic and Applied Zoology, **85**,* Article 50.

Olisah, C., Okoh, O. O., and Okoh, A. I. (2019). Occurrence of organochlorine pesticide residues in biological and environmental matrices in Africa: A two-decade review. *Heliyon,* ***5***(7), e02118.

Riaz, U., Rafi, F., Naveed, M., Mehdi, S., Munawar, M., Murtaza, G., Niazi, A. G., and Mehmood, H. (2022). Pesticide pollution in an aquatic environment. In *Freshwater pollution and aquatic ecosystems* (pp. 131–163).

Saad, M. A. H., Amuzu, A. T., Biney, C. A., Calamari, D., Imevbore, A. M., Naeve, H., and Ochumba, P. B. O. (1990). *Scientific bases for pollution control in African inland waters: Domestic and industrial organic loads.* FAO Fisheries Report No. 437, 6-24.

Schleier III, J. J., and Taglialatela-Scafati, O. (2009). Global status of DDT and its alternatives for use in vector control to prevent disease. *Environmental Health Perspectives,* ***117***(11), 1656–1663.

SeaLifeBase. (2025). *Macrobrachium vollenhovenii* (Herklots, 1857). Retrieved August 13, 2025, from https://www.sealifebase.se/summary/Macrobrachium-vollenhovenii.html

Sokolow, S. H., Huttinger, E., Jouanard, N., Hsieh, M. H., Lafferty, K. D., Kuris, A. M., Riveau, G., Senghor, S., Thiam, C., N'Diaye, A., Sarr Faye, D., and De Leo, G. A. (2015). Reduced transmission of human schistosomiasis after restoration of a native river prawn that preys on the snail intermediate host. *Proceedings of the National Academy of Sciences of the United States of America,* ***112***(31), 9650–9655.

Stehle, S., and Schulz, R. (2015). Agricultural insecticides threaten surface waters at the global scale. *Proceedings of the National Academy of Sciences of the United States of America,* ***112***(18), 5750–5755.

Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., Chu, C., and Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. *International Journal of Environmental Research and Public Health, **18***(3), 1112.

UNEP. (2020). *Global chemicals outlook II: From legacies to innovative solutions.* United Nations Environment Programme.

Unyimadu, J. P., Osibanjo, O., and Babayemi, J. O. (2018). *Levels of organochlorine pesticides in brackish-water fish from the Niger River, Nigeria. Journal of Environmental and Public Health*, 2018, Article ID 2658306.

U.S. Environmental Protection Agency (EPA). (2021). *Pesticide tolerances and exemptions for pesticide chemical residues in food.* https://www.epa.gov/pesticide-tolerances

US EPA. (2021). *Chlorpyrifos: Final rule revoking tolerances.* U.S. Environmental Protection Agency. https://www.epa.gov/ingredients-used-pesticide-products/chlorpyrifos

Walker, C. H., Sibly, R. M., Hopkin, S. P., and Peakall, D. B. (2012). *Principles of ecotoxicology* (4th ed.). CRC Press.

WHO. (2020). *Inventory of IPCS and other WHO pesticide evaluations and summary of toxicological evaluations.* World Health Organization.

Zacharia, J. T. (2011). *Ecological effects of pesticides*. In M. Stoytcheva (Ed.), Pesticides in the Modern World – Risks and Benefits (pp. 129–142).

Zhang, X., Luo, Y., Wang, J., and Yu, X. (2020). Bioaccumulation and biomagnification of persistent organic pollutants in aquatic ecosystems. *Environmental Research, **182**,* 109101.