

Effect of Boiling on Pesticide Residual Levels in the African Freshwater Prawn
(Macrobrachium vollehovenii)

BY

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DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY

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 OMONIYI TEMITOPE GRACE of the Department of Animal and Environmental Biology, Faculty of Life Sciences, University of Benin, Benin City.

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DEDICATION

This seminar report is dedicated to God Almighty. Also, to my parents, Mr and Mrs. Omoniyi, whose unwavering support and encouragement have made this possible. To my supervisor, Prof. Mrs. I. Tongo whose guidance and expertise have been of great benefit to me, God bless you all.

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ABSTRACT

Pesticide contamination in aquatic organisms poses a growing concern for both food safety and environmental health. This study evaluated the effect of boiling on the residual levels of organochlorine and organophosphate pesticides in the African freshwater prawn (*Macrobrachium vollehovenii*) obtained from markets in Benin City, Edo State, Nigeria. Prawn samples were collected from Uselu and Oba markets in August 2025. Pesticide residues were extracted and analysed using Gas Chromatography–Mass Spectrometry (GC–MS). Results showed that twenty (20) organochlorine and fourteen (14) organophosphate pesticide residues were detected in both raw and boiled prawn samples. The total concentration of organochlorines decreased from 28.42 ppb in raw samples to 23.845 ppb after boiling, indicating a slight reduction following heat treatment. Conversely, organophosphate pesticide levels increased from 8.595ppb in raw prawns to 11.405ppb in boiled samples. Among organochlorines, α -HCH, β -HCH, PP'-DDT were eliminated after boiling while Gamma-Chlordane, Alpha chlordane, PP'-DDD, Methoxy For organophosphates, Chlorpyrifos (2.405 ppb) and Phosalone (1.58 ppb) showed notably higher levels of post-boiling, whereas Isazophos and Pyrazophos were completely degraded. For both pesticide groups, the estimated daily intake (EDI) for local consumers, based on an average prawn consumption rate of 0.33 kg/day and a 60 kg adult body weight for both the raw and boiled samples, were below the acceptable daily intake (ADI), indicating minimal potential health risks. Similarly, the hazard quotient (HQ) and hazard index (HI) values for both pesticide groups were less than one (<1) for both the raw and boiled samples, implying low non-carcinogenic and carcinogenic risk to consumers. When compared with the FAO/WHO Codex and EU maximum residue limit (0.01 mg/kg for seafood), the total concentrations of organochlorine pesticides (0.028 mg/kg) exceeded the acceptable limit, indicating potential

contamination risks. These findings suggest that while boiling can reduce certain persistent organochlorine residues, it may also increase the apparent concentration of some organophosphate pesticides. Continuous monitoring and further investigation into the effects of cooking methods on pesticide dynamics are recommended to safeguard consumer health.

CHAPTER ONE

INTRODUCTION

The rising use of pesticides in farming has sparked concerns about food safety, especially those from aquatic sources (Orou *et al.*, 2024). Chemicals such as organochlorine and organophosphates compounds are commonly used in pest control because they have a long-lasting effect (Jayaraj *et al.*, 2016). However, these substances do not break down easily and can stay in the environment for a long period, eventually entering water bodies through runoff, leaching, or direct application (Islam *et al.*, 2022).

Aquatic organisms, especially crustaceans such as prawns, are susceptible to bioaccumulating these toxic substances within their tissues (Waqas *et al.*, 2024). One notable species, *Macrobrachium vollehovenii*, commonly referred to as the African river prawn, is a freshwater prawn prevalent in many regions of Nigeria and serves as a vital source of protein for local communities (Asiru and Fafioye, 2018). This species is often commercialised in regional markets, including those in Benin City, Edo State.

Consumption of contaminated prawns may pose significant health risks, as elevated pesticide residues have been associated with endocrine disruption, neurotoxicity, reproductive impairment, and carcinogenic outcomes in humans (Maia *et al.*, 2020). Recent studies have shown that food preparation methods, such as boiling, frying, or roasting, can influence the levels of pesticide residues in seafood, sometimes reducing concentrations through thermal degradation or, conversely, increasing them via moisture loss and concentration effects (Arisekar *et al.*, 2022). Although boiling remains a common cooking method in Nigeria, there is limited empirical data on how this process affects pesticide residue levels in prawns.

This study was therefore carried out to determine the presence of organophosphate and organochlorine pesticide residues in the African freshwater prawn (*Macrobrachium vollenhovenii*) and evaluate the effect of boiling on the pesticide concentrations in prawns obtained from markets in Benin City, Edo State, Nigeria

1.1 Aim and Objectives of the Study

The primary aim of this study is to evaluate the effect of boiling on the concentration of organochlorine and organophosphate pesticide residues in *Macrobrachium vollenhovenii* sourced from selected markets (Uselu and Oba market) in Benin City, Edo State.

The specific objectives of the study are:

1. To identify and quantify the levels of organochlorine and organophosphate pesticide residues in *Macrobrachium vollenhovenii* after boiling.
2. To compare the pesticide residue levels in boiled prawn samples with standard safety limits.
3. To assess whether boiling significantly reduces pesticide concentrations to levels considered safe for human consumption.
4. To evaluate potential health risks associated with the consumption of boiled prawns based on the detected pesticide levels.

CHAPTER TWO

LITERATURE REVIEW

2.0 PESTICIDES

2.1 Definition and Classification of Pesticides

Pesticides are chemical or biological agents designed to prevent, eradicate, repel, or reduce the impact of pests such as insects, weeds, fungi, nematodes, and rodents. They serve as vital instruments within the realms of agriculture, public health, and environmental management. Nonetheless, due to the toxicity and environmental persistence of numerous pesticides, the implementation of stringent regulations and responsible utilization is imperative (Ware & Whitacre, 2004).

Pesticides can be classified according to their chemical composition, mode of action, or target organism. Among the most extensively studied chemical classes are organophosphates, organochlorines, carbamates, and pyrethroids.

2.1.1 Organophosphates

Organophosphates are esters of phosphoric acid and act by irreversibly inhibiting acetylcholinesterase, an enzyme critical for neurotransmission. This inhibition results in the accumulation of acetylcholine at nerve endings, leading to overstimulation, paralysis, and death in insects (Costa, 2006). These compounds, including malathion, parathion, and chlorpyrifos, have been widely employed in agriculture and vector control. However, due to their high acute toxicity in humans and wildlife, especially through dermal or inhalation exposure, their usage has come under increasing regulatory scrutiny (Jaga and Dharmani, 2003).

2.1.2 Organochlorines

Organochlorines are characterized by the presence of multiple chlorine atoms, which contribute to their chemical stability and environmental persistence. These compounds act on the central nervous system by disrupting the movement of sodium and potassium ions across nerve membranes, thereby impairing neural signal transmission (ATSDR, 2002). Notable examples include DDT, aldrin, and dieldrin. Although once popular due to their effectiveness and long residual activity, many organochlorines have been banned or restricted globally under agreements such as the Stockholm Convention, owing to their bioaccumulation in the food chain and endocrine-disrupting properties (Van den Berg, 2009).

2.1.3 Carbamates

Carbamates are structurally like organophosphates and share a comparable mode of action: acetylcholinesterase inhibition, but this inhibition is reversible, resulting in shorter-lived toxic effects (Ecobichon, 2001). Examples such as carbaryl and aldicarb are widely used in agriculture and horticulture. Though generally considered less toxic than organophosphates, carbamates still pose risks to non-target organisms, including pollinators, aquatic species, and humans, especially with repeated exposure (Marrs, 2012).

2.1.4 Pyrethroids

Pyrethroids are synthetic derivatives of natural pyrethrins, which are extracted from *Chrysanthemum* flowers. They function by modifying the gating kinetics of voltage-sensitive sodium channels in insect neurons, leading to prolonged depolarization and cell death (Casida, 2017).

These compounds, such as cypermethrin, deltamethrin, and permethrin, are widely used due to their rapid knockdown effect, low toxicity to mammals, and short environmental half-life. Nevertheless, resistance development and toxicity to aquatic invertebrates have raised ecological concerns (Bradberry *et al.*, 2005). Each pesticide class has its own chemical properties, mode of action, environmental fate, and toxicity profile. While they have undeniably improved agricultural yields and controlled vector-borne diseases, their indiscriminate use poses threats to human health, biodiversity, and ecosystem function. Regulatory frameworks and the implementation of Integrated Pest Management (IPM) strategies are crucial for mitigating these risks and ensuring the sustainable use of chemical pesticides (FAO, 2020).

2.2 Sources of Pesticide Contamination in Aquatic Environments

Pesticide contamination in aquatic ecosystems is a growing global concern, particularly in regions where chemical inputs into agriculture, aquaculture, and industry remain poorly regulated. Water bodies such as rivers, lakes, estuaries, and groundwater systems are particularly vulnerable to such contamination due to their open and interconnected nature. The primary sources contributing to pesticide accumulation in aquatic environments include agricultural runoff, aquaculture discharge, and industrial waste.

2.2.1 Agricultural Runoff

One of the most significant pathways through which pesticides enter aquatic systems is through surface runoff from agricultural land. Following pesticide application, rainfall or irrigation can transport unabsorbed residues into nearby streams, rivers, and lakes. This is especially pronounced during periods of heavy rainfall or in areas with sloped topography and poor soil structure, where infiltration is limited and erosion is prevalent (Schulz, 2004).

Runoff contamination is influenced by several factors, including the chemical properties of pesticide (e.g., water solubility, half-life), soil composition, and application techniques. For instance, pesticides with high water solubility, such as atrazine, are more likely to be leached into aquatic environments, whereas compounds that bind strongly to soil particles may be transported as particulate-bound contaminants (Gavrilescu, 2005). These pesticides can exert toxic effects on non-target aquatic organisms, disrupt food webs, and impair ecosystem services such as water purification and biodiversity maintenance. Long-term accumulation can also result in chronic toxicity in fish, amphibians, and benthic invertebrates (Stehle & Schulz, 2015).

2.2.2 Aquaculture Practices

The expansion of intensive aquaculture systems has introduced another pathway for pesticide entry into water bodies. In many aquaculture operations, especially in shrimp and fish farming, chemicals such as organophosphates, pyrethroids, and biocides are employed to control parasites, bacterial infections, and algal blooms (Rico *et al.*, 2012).

These substances are often applied directly to the water or incorporated into fish feed. However, due to poor containment systems, a significant portion may escape into surrounding aquatic environments, particularly in open pond or cage culture systems. Moreover, residues in uneaten feed and fecal matter contribute to sediment contamination, where they may persist and affect benthic organisms (BurrIDGE *et al.*, 2010).

While pesticides are used to ensure aquaculture productivity, their unregulated or excessive application can result in the contamination of estuaries, mangroves, and coastal zones, often overlapping with areas of ecological and economic importance.

2.2.3 Industrial Waste and Effluents

In addition to agricultural and aquacultural sources, industrial waste discharges are a major contributor to pesticide pollution in aquatic systems. Industries involved in the manufacture, formulation, packaging, and storage of pesticides may release untreated or partially treated effluents containing a range of toxic residues into surface waters (Köck-Schulmeyer *et al.*, 2013).

These contaminants often include persistent organic pollutants (POPs), which can bioaccumulate in aquatic food chains and pose long-term risks to both ecosystems and human health. Inadequate waste treatment infrastructure, particularly in developing countries, exacerbates the problem. For instance, wastewater from pesticide manufacturing plants has been found to contain high levels of chlorinated hydrocarbons and solvent residues, many of which are resistant to natural degradation processes (Carvalho, 2017). Moreover, accidental spills and leakages from storage facilities also contribute to localized contamination hotspots, especially near industrial zones situated close to river systems or coastal areas.

The contamination of aquatic environments by pesticides arises from multiple, often overlapping sources. While agricultural runoff remains the predominant contributor due to the scale of pesticide use, increasing concerns have been raised about aquaculture discharges and industrial effluents. Each of these pathways introduces unique chemical profiles and ecological challenges, underscoring the need for integrated management approaches and enforcement of environmental regulations. Improved waste handling, buffer zones, and sustainable pest management practices are essential to reduce the impact of pesticide contamination on aquatic ecosystems.

2.3 Pesticide Bioaccumulation in Aquatic Organisms: Mechanisms and Influencing Factors

Bioaccumulation refers to the gradual accumulation of substances, such as pesticide residues, in living organisms. In aquatic ecosystems, accumulation can occur through uptake from water, ingestion of contaminated food or sediments, and absorption through skin or gills. Understanding the pathways and factors that govern this accumulation is critical for assessing ecological risks and human exposure via consumption of aquatic biota (Arnot and Gobas, 2006; Akinsanya *et al.*, 2015).

2.3.1 Mechanisms of Bioaccumulation

- i. Bioconcentration from Water:** Aquatic organisms can absorb pesticides directly from their surrounding water through gills or exposed surfaces (e.g., skin in amphibians, exoskeleton in invertebrates). Lipophilic pesticides: those with high octanol-water partition coefficients (K_{ow}) — tend to accumulate in fatty tissues because they dissolve more readily into lipid phases than into water (Rand *et al.*, 1995). Persistent organochlorines (OCs) such as DDT and its metabolites resist degradation, prolonging retention in organisms (Akinsanya *et al.*, 2015).
- ii. Dietary Uptake:** Another route is ingestion: organisms feed on prey, algae, or detritus that already contain residues. Predators or omnivores above lower trophic levels may thus accumulate more pesticide burden (Gobas *et al.*, 1999). In Nigerian lagoons, for example, fish and invertebrates feeding on contaminated plankton or sediment-dwelling organisms show measurable burdens of organochlorine pesticides (Akinsanya *et al.*, 2015).
- iii. Sediment-Bound and Particulate Uptake:** Many pesticides attach to suspended particles or settle into sediment. Bottom-feeding species, benthic invertebrates, and

organisms that ingest sediment directly are exposed via this reservoir. Once in sediment, degradation is often slower; organisms moving between sediment and water may pick up these bound pesticides (Gavrilescu, 2005; Akinsanya *et al.*, 2015).

- iv. **Metabolism and Excretion:** Whether a pesticide accumulates depends also on how well the organism can transform (detoxify) or excrete the compound. Some pesticides are metabolised quickly, while others resist biotransformation. Genetic, enzymatic, and physiological differences between species affect retention time. Persistent pesticides with low rates of metabolism (e.g., many OCs) have higher accumulation potential (Muir & Howard, 2006; Akinsanya *et al.*, 2015).

2.3.2 Factors influencing pesticide bioaccumulation in aquatic organisms.

Several interacting factors modulate the degree of bioaccumulation:

1. Chemical Properties of Pesticides

- i. **Lipophilicity and persistence:** More lipophilic and persistent compounds tend to accumulate more. For example, organochlorine pesticides such as γ -HCH (lindane), aldrin, and DDT show higher concentrations in fish tissues in Nigerian waters. Akinsanya *et al.* (2015) documented γ -HCH and lindane residues in sediments and biota of Lagos Lagoon at levels reflecting high persistence.
- ii. **Solubility and volatility:** Highly soluble pesticides may leach out rather than bind to tissues; volatile ones may dissipate. These properties shape exposure routes and accumulation kinetics (Rand *et al.*, 1995).

Species-Level Traits

- i. **Trophic Level:** Organisms higher in the food chain (predators) often show biomagnification: pesticide concentration rising through successive trophic transfers. Studies in Lagos Lagoon (Akinsanya *et al.*, 2015) showed that larger predatory fish had higher accumulation compared to primary consumers and invertebrates.
- ii. **Lipid Content:** Species with higher fat content tend to store more lipophilic pesticides. Fish that store lipids in muscle or organs will retain pesticide residues longer.
- iii. **Growth, Age, Size:** Older and larger fish can accumulate more over their lifetimes due to longer exposure; also, slow growth or long lifespans magnify bioaccumulation potential.

2. Environmental Conditions

- i. **Sediment Composition and Organic Matter:** Sediments rich in organic content tend to bind more hydrophobic pesticides, increasing the sediment reservoir from which benthic organisms acquire toxins. (Akinsanya *et al.*, 2015).
- ii. **Temperature, pH, Salinity:** Higher temperatures may increase uptake and metabolism. Salinity and pH may influence pesticide speciation, solubility, and thus bioavailability.
- iii. **Hydrology and Seasonality:** In regions with wet and dry seasons, pulses of pesticide runoff occur with rainfall, increasing concentrations in water and

sediment; dry seasons may concentrate residues in sediments and biota (Edjere *et al.*, 2020 in Warri River study) (Edjere, Ukpebor and Okieimen, 2020).

3. Exposure Duration and Frequency: Repeated or chronic exposure, even at low levels, often results in cumulative accumulation, especially for persistent compounds. For example, the study in the Warri River found that several organochlorine pesticides remained detectable across both dry and wet seasons (Edjere *et al.*, 2020).

4. Anthropogenic Factors

- i. **Agricultural practices:** Overuse, improper application, and timing relative to rainfall influence the amount of pesticide entering aquatic environments.
- ii. **Regulatory oversight and mitigation:** Lack of enforcement of pesticide regulation, absence of buffer zones, poor waste management all enhance the likelihood of bioaccumulation.

Bioaccumulation in aquatic organisms is not governed by a single factor but by a nexus of chemical characteristics, organismal biology, and environmental conditions. Nigerian studies show that persistent pesticide classes, especially organochlorines, continue to accumulate in sediments and biota of lagoons and rivers. These findings underscore risks to ecosystems and food safety. For your project, drawing on local studies strengthens the relevance; just ensure to compare across different sites, species, and pesticide types.

2.4 Health Impacts of Pesticides: Short- and Long-Term Effects on Humans

Pesticides, although indispensable in contemporary agriculture and public health initiatives, present considerable hazards to human health. These hazards can be categorised into short-term

(acute) and long-term (chronic) effects. The following is a summary of both, drawing on reports from the World Health Organisation (WHO), the Food and Agriculture Organisation (FAO), and peer-reviewed research studies.

Short-term effects of pesticide exposure occur soon after exposure and often depend on dose, route of exposure (inhalation, dermal contact, ingestion), and the toxicity of the pesticide. Some of the acute effects include:

- i. Irritation of eyes, skin, and mucous membranes; redness, itching, and burning sensations.
- ii. Respiratory symptoms: coughing, difficulty breathing, throat irritation.
- iii. Neurological symptoms: headache, dizziness, nausea, vomiting, fatigue.
- iv. Gastrointestinal symptoms: diarrhoea, abdominal pain.
- v. In more severe cases: organ dysfunction (e.g., respiratory failure, kidney or liver impairment).

These kinds of effects are particularly common among agricultural workers, pesticide applicators, and people in proximity to sprayed fields without adequate protection. According to a *WHO fact sheet* on pesticide residues in food, “when people come into contact with large quantities of pesticides, the result may be acute poisoning ...”

A systematic review (Hu *et al.*, 2015) of farmers in China found that in the short term (days to weeks after spraying), there were measurable alterations in:

- i. blood cell counts (e.g., decreased haemoglobin, platelets),
- ii. hepatic and renal function, and

- iii. nerve conduction (velocity and amplitude) in peripheral nerves.

Acute unintentional pesticide poisoning remains a large global problem. A systematic review supplemented by WHO mortality data estimated about 385 million cases of acute unintentional pesticide poisoning annually worldwide, including around 11,000 fatalities. Many of these non-fatal cases report relatively mild or moderate symptoms, but cumulatively they represent a substantial public health burden.

Long-term exposure repeated or continuously over months, years, or even decades can lead to a variety of serious health outcomes. These effects can persist long after exposure has ceased, may be cumulative, and often are harder to attribute specifically to pesticides (because of multiple factors), but there is credible evidence from the WHO, FAO, and other studies.

Some of the major chronic effects include:

- i. Cancer: Exposure to certain pesticide classes has been associated with increased risk of various cancers, including leukaemia, non-Hodgkin lymphoma, and possibly cancers of the breast, prostate, lung, and skin. WHO/FAO's pesticide residue management and risk evaluation efforts recognise the carcinogenic potential of some pesticide residues.
- ii. Neurological Disorders Chronic exposure may lead to neurodegenerative diseases (e.g., Parkinson's disease), impairment of peripheral nerves, cognitive decline, developmental neurotoxicity in children, and delayed effects on neural conduction. The cohort study in China demonstrated reduced nerve conduction amplitudes and sensory nerve abnormalities after long-term exposure.
- iii. Endocrine Disruption and Reproductive Effects: Some pesticides act as endocrine disruptors, interfering with hormonal systems. Outcomes linked in studies include

fertility decline, birth defects, spontaneous abortions, and reduced sperm quality. FAO / WHO defines many “Highly Hazardous Pesticides” in part by their potential reproductive, mutagenic, or carcinogenic effects.

- iv. **Developmental Effects on Children and Prenatal Exposure:** Children are more vulnerable due to their developing organs, different metabolic rates, and behaviours that increase exposure (hand-to-mouth, playing on soil, etc.). Prenatal exposure can lead to low birth weight, developmental delays, and congenital malformations.
- v. **Other Chronic Health Issues**
 - a. Effects on immune system function, making individuals more susceptible to infections or allergic reactions.
 - b. Effects on organs such as the liver, kidney (chronic damage), lung (e.g., asthma, chronic respiratory conditions).
 - c. Potential for metabolic disorders (e.g., effects on glucose metabolism), though evidence is less consistent.
 - d. Possible cumulative effects of low-dose exposures via residues in food, water, or the environment. WHO/FAO’s work on pesticide residues in food emphasises that chronic exposure through diet, over a lifetime, is a concern.

2.5 Pesticide Residues in Seafood

Pesticide contamination in seafood has become a significant public health and environmental concern worldwide. Aquatic organisms, particularly fish and prawns, are exposed to pesticides through direct contact with contaminated water, sediment, and food

chains. These compounds, many of which are persistent organic pollutants (POPs), accumulate in fish tissues over time, potentially entering the human diet and posing chronic health risks. Globally, several studies have documented the presence of pesticide residues in aquatic species, including both freshwater and marine organisms. In South Korea, Kim et al. (2024) assessed 300 seafood samples using a modified Quenchers method coupled with gas chromatography-tandem mass spectrometry (GC-MS/MS). They found eight different pesticide residues, including DDT, DDE, and pendimethalin, across various samples. Importantly, the residue levels were below established maximum residue limits (MRLs), and the associated health risk indices indicated minimal risk to consumers. Similar trends have been observed in China, where multi-residue monitoring of aquaculture products revealed detectable levels of several pesticides such as atrazine and pyrethroids, albeit mostly within safety thresholds (Sarkar *et al.*, 2022). These studies underscore the persistence of pesticide residues in aquatic food sources, even in regions with advanced agricultural management and monitoring systems.

Within the West African context, particularly in Nigeria, research has increasingly concentrated on the levels and implications of pesticide residues in fish and other aquatic organisms. This focus is motivated by the high reliance on fish as a source of protein and the extensive, often unregulated, utilization of agrochemicals. Ezemonye et al. (2015) carried out a study across three rivers in Edo State—Illushi, Owan, and Ogbesse—and identified detectable concentrations of organochlorine pesticides (OCPs), such as BHC isomers, heptachlor, aldrin, and DDT, in two commonly consumed fish species: *Clarias gariepinus* and *Tilapia zilli*. Their findings indicated that residue levels were generally higher in *C. gariepinus* than in *T. zilli*, with some values surpassing internationally

recognized safety limits. The study concluded that prolonged exposure through the ingestion of contaminated fish could pose a substantial health risk.

Further evidence from the Owan River, as documented by Ogbeide *et al.* (2015), revealed measurable levels of pesticide residues in water, sediments, and fish samples. Here, residues such as aldrin and dieldrin were particularly concerning, as they were found in concentrations above reference safety values, particularly in fatty tissues and bottom-dwelling species. Mshelia *et al.* (2022) reported similar findings in the Benue River in Adamawa State. Their study observed elevated concentrations of aldrin and dieldrin in fish tissues, with some values surpassing WHO and FAO limits. These findings were reinforced by hazard quotient and estimated daily intake calculations, which indicated that certain fish species could present moderate to high health risks to frequent consumers, especially vulnerable groups such as children and pregnant women.

In the Niger Delta region, where intense agricultural and industrial activities converge, the issue of pesticide contamination in aquatic life is even more pronounced. In Akwa Ibom State, for example, Moses *et al.* (2022) investigated fish from the Nwaniba River and identified dieldrin as a dominant residue. The calculated hazard indices for several samples were greater than 1, particularly among samples of Nile tilapia and upside-down catfish, suggesting potential health risks from long-term dietary exposure. Likewise, a study on smoked fish sold in South-West Nigerian markets found pesticide residues, particularly aldrin and heptachlor epoxide, in concentrations that exceeded reference doses (Usifoh *et al.*, 2019). The persistence of these compounds despite processing techniques such as smoking or drying highlights the difficulty in mitigating exposure solely through post-harvest handling.

In addition to fish, the presence of pesticide residues in prawns and crustaceans is also a growing concern, though less extensively studied. Studies from other West African countries suggest the issue is region wide. For instance, a study conducted along Ghana's Densu River Basin detected OCPs including γ -HCH, DDT and its metabolites, aldrin, and endosulfan in several edible fish species (Darko *et al.*, 2013). Although many of the detected levels were within international MRLs, the study raised concerns about the cumulative effects of multiple residues and their potential to disrupt endocrine systems in humans. In Cameroon, however, recent studies yielded a contrasting result. Meli *et al.* (2023) screened 259 pesticide residues in fish species from the Menoua River and found none above WHO safety limits, suggesting regional variability influenced by agricultural practices, enforcement of pesticide regulations, and environmental factors.

Overall, the reviewed literature reveals several consistent findings. Organochlorine pesticides, though banned or restricted in many countries, continue to be detected in Nigerian and West African aquatic systems. This persistence is likely due to their environmental stability and bioaccumulative properties. Fish species with higher fat content or benthic feeding habits tend to show elevated levels of contamination. Furthermore, some pesticide residues in Nigerian waters and fish exceed international safety thresholds, pointing to regulatory gaps and a need for more stringent monitoring. The health implications of these findings are particularly concerning, given the reliance on fish as a primary protein source in many Nigerian and West African households.

While international studies often report low health risks due to better regulatory control and effective agricultural practices, findings from Nigeria and surrounding countries present a mixed picture. The presence of hazardous pesticide residues above

recommended limits, particularly in regions with high pesticide usage and limited environmental oversight, warrants urgent action. Regular surveillance, public education on pesticide use, and improved enforcement of existing bans on persistent pollutants are crucial steps toward safeguarding public health and ensuring the sustainability of aquatic ecosystems.

2.6 Effects of Boiling on Pesticide Residues

- i. **Thermal Degradation:** Heat applied during boiling can break down pesticide molecules, especially those with unstable bonds (e.g., ester, carbamate bonds), converting them into less toxic or inactive compounds. (Fenner *et al.*, 2013)
- ii. **Leaching into Cooking Water:** Pesticides that are water-soluble or loosely bound to surface residues can migrate into the boiling water; when the water is discarded, residue in the food is reduced. For example, in a study with beans boiled in Lagos, Nigeria, boiling decreased residues in ~86% of samples, with water-soluble organophosphate and carbamate pesticides showing high reductions. (Ogah *et al.*, 2017) 86% of samples showed reduction; organophosphates 24-100% and carbamates 20-100%) (Ogah, Coker & Adepoju-Bello, 2011).
- iii. **Chemical Transformation:** Boiling may promote hydrolysis, oxidation, or rearrangement reactions. Pesticide molecules may transform into metabolites; for example, in environmental water systems, chlorpyrifos undergoes hydrolysis and photodegradation under certain conditions in Nigeria (Ikpeni & Ejiogu *et al.*, 2014), which shows how chemical transformation proceeds under related conditions, though not exactly boiling. (Ukpebor *et al.*, 2014).

2.7 Factors Influencing the Reduction of Pesticides in Foods.

Boiling plays a significant role in the reduction of pesticide residues in foods. Longer boiling periods generally provide more time for both degradation and leaching. For example, in the bean study conducted in Lagos, samples boiled for one hour at high temperatures showed substantial reductions ranging from 24% to 100% for some pesticide types when compared to raw beans.

Temperature also influences pesticide reduction. While boiling water typically reaches around 100 °C at sea level, the actual effective temperature, along with agitation, can impact how quickly pesticides degrade. High temperatures enhance thermal degradation and chemical transformation.

The type of pesticide used, including its chemical class, stability, solubility, and volatility, is another crucial factor. Organochlorines, for instance, are more persistent and less reduced by boiling compared with organophosphates and carbamates. In the Lagos bean example, organochlorine pesticides showed only 9% to 32% reductions, whereas organophosphate and carbamate classes showed reductions of up to 100%. Water-soluble or polar pesticides tend to leach more easily, while lipophilic, non-polar ones bind more strongly in fatty or waxy tissues.

The food matrix also affects pesticide reduction. Factors such as surface area, whether the food is peeled or not, and whether it is cut or whole, all influence the exposure of pesticide residues to water and heat. Foods with fat content tend to bind lipophilic residues, while those with porous tissues, such as beans and leaves, allow boiling water to penetrate more effectively

In Nigerian studies of tubers and vegetables, although boiling was not always tested, residue levels were found to differ across food matrices (e.g., tubers versus leafy vegetables), likely due

to these matrix differences. This was observed in the "Evaluation of Pesticide Residues in Common Food Tubers, Nigeria."

CHAPTER THREE

MATERIALS AND METHOD

3.1 DESCRIPTION OF STUDY AREA

Benin City, the capital and largest urban centre in Edo State, lies approximately 40 kilometres north of the Benin River and about 320 kilometres east of Lagos. The city serves as an important administrative and commercial hub in southern Nigeria and experiences a tropical climate characterised by distinct wet and dry seasons. Prawn samples were collected from two major markets, Oba Market and Uselu Market, both located in Benin City, Edo State, Nigeria (Figure 3.1).

Oba Market, situated at the heart of Benin City, is one of the largest traditional markets in the state and serves as a major trading point for a wide range of food items, including fish and prawns sourced from different aquatic environments. Its central location and high seafood turnover make it a suitable site for evaluating the level of pesticide residues in prawns supplied from diverse sources. Similarly, Uselu Market, located along Uselu–Lagos Road in Benin City, is a well-established commercial centre known for its vibrant seafood trade. The market attracts vendors from neighbouring riverine areas who supply freshly caught prawns and other aquatic produce. Sampling from both markets provided a representative overview of the potential pesticide contamination in prawns available for human consumption within Benin City.

3.2 SAMPLE COLLECTION

The freshwater prawn species (*Macrobrachium vollehovenii*) (Plate 3.1) were obtained from seafood vendors at Oba Market and Uselu Market in Benin City, Edo State, Nigeria. Immediately after collection, the samples were placed in ice-packed containers to preserve freshness and prevent degradation during transportation to the laboratory. Upon arrival, the prawns were identified to species level based on diagnostic morphological characteristics following the FAO Species Identification Guide (Holthuis, 1980). Each specimen was initially weighed whole, then carefully deshelled, reweighed, and the tissue weight recorded. The deshelled edible portions of the prawns (Plate 3.3) were placed in clean, non-reactive bottles, packed with ice to maintain a low temperature, and transported to the laboratory for pesticide residue analysis. From the deshelled samples, two prawn samples were boiled in deionised water for 10 minutes to evaluate the effect of heat treatment on pesticide residue levels, while the remaining samples were analysed raw. A total of twenty (20) organochlorine and thirteen (13) organophosphate pesticide residues were examined in the African freshwater prawn (*Macrobrachium vollehovenii*) collected from the two markets in Benin City, Edo State.

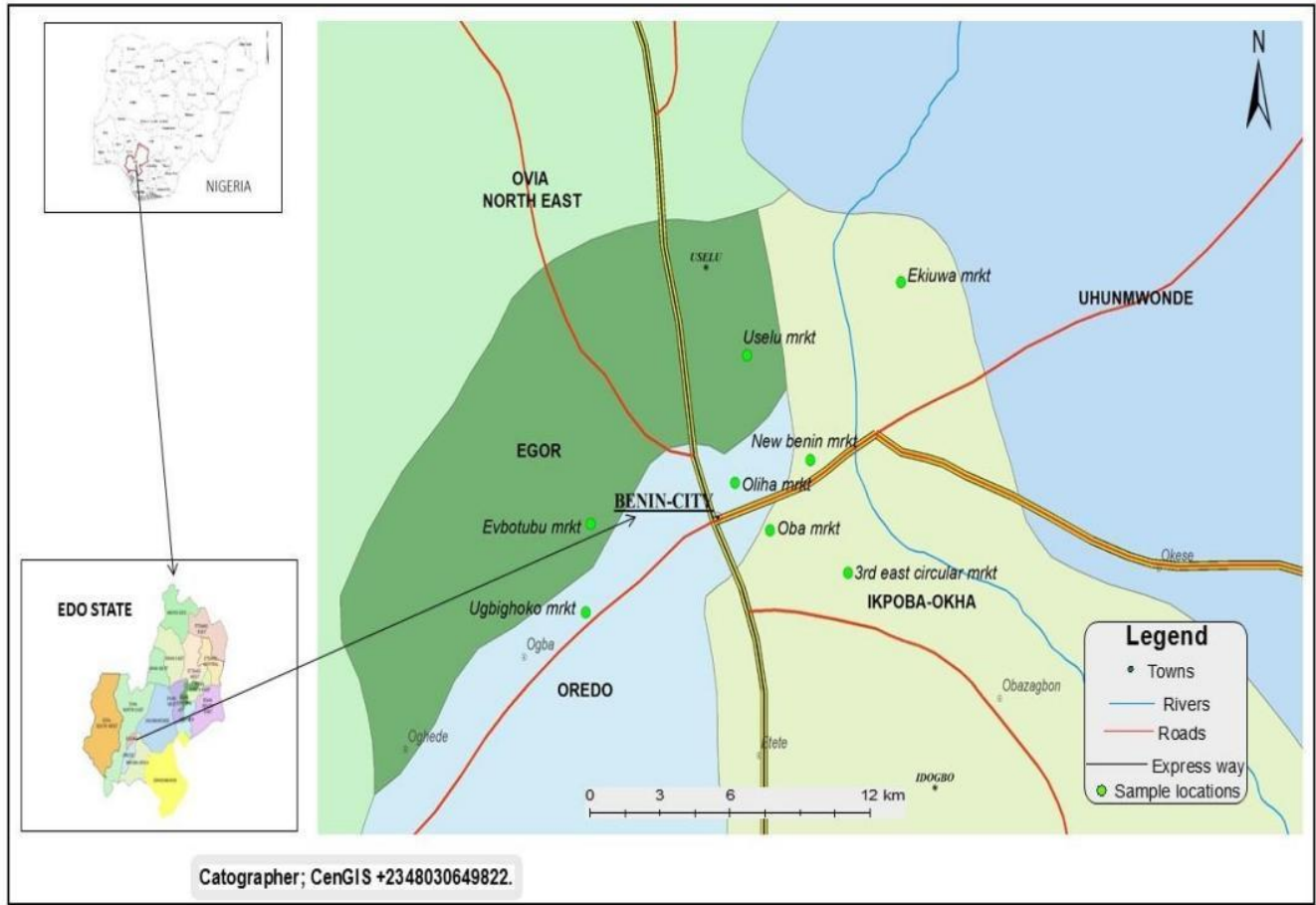


Figure 3.1. Map of Edo State showing Oba Market and Useju Market

3.3 Pesticide Extraction, Cleanup and Analysis

Pesticide residues in both raw and boiled prawn samples were analysed following the procedure outlined by the U.S. Environmental Protection Agency (USEPA, 2007) with slight modifications. The analytical process consisted of three main stages: extraction, clean-up, and instrumental detection using Gas Chromatography–Mass Spectrometry (GC–MS).

For the raw samples, 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 promote the release of pesticide residues from the tissue matrix. The extracts were then allowed to stand for 24 hours to ensure complete solvent–sample interaction before being filtered through Whatman No. 1 filter paper.



Plate 3.1: *Macrobrachium vollenhoveni*



Plate 3.2: *Macrobrachium vollenhovenii* on a weighing balance.



Plate 3.3: *Macrobrachium vollenhovenii* after deshelling.



Plate 3.4: *Macrobrachium vollenhovenii* after boiling for ten minutes.

For the boiled samples, whole prawns were first boiled in deionised water for 10 minutes, drained, homogenized, and then subjected to the same extraction and clean-up procedures as the raw samples. This allowed for a direct comparison of pesticide concentrations before and after thermal processing.

The filtrates obtained from both sample types were cleaned up using a glass chromatographic column packed with activated silica gel. Elution was carried out with n-hexane, and the eluates were concentrated to approximately 1 mL under a gentle stream of nitrogen gas. The concentrated extracts were then transferred into 2 mL Teflon-lined screw-cap vials for GC–MS analysis. Instrumental analysis was performed using an Agilent 6890N Gas Chromatograph coupled with an Agilent 5973 Mass Selective Detector (MSD). The GC oven temperature program was set to begin at 80 °C and then ramped in two stages to 300 °C. Identification and quantification of pesticide residues were based on comparisons of retention times and mass spectral data with those of certified analytical standards. A total of twenty (20) organochlorine and thirteen (13) organophosphate pesticide residues were assessed in both raw and boiled *Macrobrachium vollehovenii* samples collected from Oba and Uselu Markets in Benin City, Edo State.

3.4 Assessment of human health risk

The human health risk assessment was conducted to evaluate the potential adverse effects associated with the consumption of *Macrobrachium vollehovenii* 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-

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)

carcinogenic and carcinogenic risks. The parameters, equations, and values applied in the calculations are summarised in Table 3.1.

3.4.1 Estimated Daily Intake (EDI)

The Estimated Daily Intake (EDI) of pesticide residues in *M. vollehovenii* 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 (C_p), the average daily ingestion rate of crustaceans (IFR), and the average adult body weight (BW).

$$\text{Estimated Daily Intake (EDI)} = \frac{C_p \times \text{IFR}}{\text{BW}} \quad \text{Equation 1}$$

3.4.2 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 carcinogenic risk was estimated using Equation 3.

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

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

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).

$$HI = \sum_{(i=1)}^n HQ_i$$

Equation 4

3.5 Data analysis

Data was statistically analysed using Excel (2010). Mean, standard deviation, standard error, minimum, and maximum values were used to represent pesticide concentration in both the raw and boiled 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 and between the raw and boiled samples.

CHAPTER FOUR

RESULTS

4.1 Organochlorine Pesticide Residues in the Raw Prawn (*Macrobrachium vollehovenii*) samples

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, endosulfan II, P, P'-DDT, endrin aldehyde, endosulfan sulfate, methoxychlor, and endrin ketone (Table 4.1), with mean concentrations ranging from 0.0065 to 2.975 ppb. The total mean concentration of OCPs was 28.42 μ g/kg, indicating a significant level of contamination in the prawns. The highest mean concentration was recorded for p,p'-DDD (2.975ppb), followed by Endosulfan I (2.9ppb) and Endrin Aldehyde (2.615ppb). There was, however, no significant ($p>0.05$) in concentrations between the OCPs in the prawn samples. Heptachlor epoxide was not detected (Table 4.1).

4.2 Effect of Boiling on Organochlorine Pesticide Residues in the Prawn (*Macrobrachium vollehovenii*) samples

The results of pesticide residue analysis in *Macrobrachium vollehovenii* revealed varying effects of boiling on the concentrations of organochlorine (OCPs) (Table 4.2). The organochlorine pesticide residues detected in the boiled prawn samples included γ -HCH (lindane), heptachlor, δ -HCH, aldrin, heptachlor epoxide, alpha-chlordane, endosulfan I, p,p'-DDE, dieldrin, p,p'-DDD, endosulfan II, endrin aldehyde, and methoxychlor (Table 4.2). The mean concentrations ranged from 0 to 5.93 ppb, with a total mean concentration of

0.023845 μ g/kg, representing a 16.098% reduction compared to the raw samples (0.02842 μ g/kg). The highest mean concentration was recorded for PP'DD (5.93pbb), followed Gamma chlordanes (2.285 pbb) and Alpha chlordanes (1.865 pbb) while PP'DDT, Alpha HCH, Beta HCH were not detected.

**Table 4.1: Mean concentration of Organochlorine Pesticides found in Raw Prawn Samples
(*Macrobrachium vollehoventi*)**

Target Compounds	Mean± SD	SE	%	Min	Max
α – HCH	0.805 ± 1.138	0.805	2.833	0	1.61
β-HCH	0.35 ± 0.495	0.35	1.232	0	0.7
γ - HCH (LINDANE)	1.73 ± 0.396	0.28	6.087	1.45	2.01
Heptachlor	1.355 ± 1.916	1.355	4.768	0	2.71
δ-HCH	0.815 ± 1.153	0.815	2.868	0	1.63
Aldrin	1.005 ± 0.997	0.705	3.536	0.3	1.71
Heptachlor Epoxide	0	0	0	0	0
Gamma- Chlordane	1.435 ± 0.601	0.425	5.049	1.01	1.86
Alpha-Chlordane	0.36 ± 0.509	0.36	1.267	0	0.72
Endosulfan I	2.9 ± 0.509	0.36	10.204	2.54	3.26
P,p'-DDE	1.32 ± 0.424	0.3	4.645	1.02	1.62
Dieldrin	2.35 ± 3.323	2.35	8.269	0	4.7
Endrin	2.615 ± 3.698	2.615	9.201	0	5.23
P,P'-DDD	2.975 ± 2.920	2.065	10.468	0.91	5.04
Endsulfan II	2.185 ± 0.629	0.445	7.688	1.74	2.63
P,P'-DDT	1.915 ± 2.708	1.915	6.738	0	3.83
Endrin aldehyde	0.725 ± 1.025	0.725	2.55102	0	1.45
Endosulfan sulfate	1.17 ± 1.655	1.17	4.116819	0	2.34
Methoxychlor	0.065 ± 0.092	0.065	0.228712	0	0.13
Endrin ketone	2.345 ± 3.316	2.345	8.251232	0	4.69
TOTAL	28.42 ± 1.791		100		

Table 4.2: Mean concentration of Organochlorine Pesticides found in Boiled Prawn Samples (*Macrobrachium vollehoveni*)

Target Compounds	Mean \pm SD	SE	%	Min	Max
α - HCH	0	0	0	0	0
β - HCH	0	0	0	0	0
γ - HCH (LINDANE)	0.13 \pm 0.141	0.1	0.545	0.03	0.23
Heptachlor	0.795 \pm 0.120	0.085	3.334	0.71	0.88
δ -HCH	0.68 \pm 0.962	0.68	2.851	0	1.36
Aldrin	0.73 \pm 1.032	0.73	3.061	0	1.46
Heptachlor Epoxide	1.315 \pm 1.860	1.315	5.514	0	2.63
Gamma- Chlordane	2.285 \pm 2.058	1.455	9.583	0.83	3.74
Alpha-Chlordane	1.865 \pm 2.638	1.865	7.821	0	3.73
Endosulfan I	1.525 \pm 1.308	0.925	6.395	0.6	2.45
P,p'-DDE	1.22 \pm 1.725	1.22	5.116	0	2.44
Dieldrin	0.795 \pm 1.124	0.795	3.334	0	1.59
Endrin	0.575 \pm 0.785	0.555	2.411	0.02	1.13
P,P'-DDD	5.93 \pm 0.933	0.66	24.869	5.27	6.59
Endsulfan II	1.635 \pm 0.544	0.385	6.857	1.25	2.02
P,P'-DDT	0	0	0	0	0
Endrin aldehyde	0.395 \pm 0.559	0.395	1.657	0	0.79
Endosulfan sulfate	0.93 \pm 1.315	0.93	3.900	0	1.86
Methoxychlor	1.5 \pm 2.121	1.5	6.291	0	3
Endrin ketone	1.54 \pm 2.178	1.54	6.458	0	3.08
TOTAL	23.845 \pm 1.336		100		

4.3 Organophosphate Pesticide Residues in the Raw Prawn (*Macrobrachium vollehovenii*) samples

The organophosphate pesticide residues detected included Diazinon, Isazophos, Chloropyriphos-methyl, Pirimiphos Methyl, Pirimiphos Ethyl, Quinalphos, Chlorpyrifos, Phosalone, Pyrazophos, Azinphos-ethyl, Pyraclofos, Ethyl paranitrophenyl phenylphosphonothioate (EPN) (Table 4.3), with mean concentrations ranging from 0 to 1.695 ppb. The total mean concentration of OPPs was 0.008595 μ g/kg, indicating a significant level of contamination in the prawns. The highest mean concentration was recorded for Pirimiphos ethyl (1.695 pbb) followed by Pyraclofos (1.395pbb) and Pirimiphos methyl (1.35pbb). There was, however, no significant ($p>0.05$) in concentrations between the OPPs in the prawn samples. Compounds such as 1,3, dimethyl 2-nitrobenzene were not detected (Table 4.3).

4.4 Effect of Boiling on Organophosphate Pesticide Residues in the Prawn (*Macrobrachium vollehovenii*) samples

The organophosphate pesticide residues identified in the boiled samples included diazinon, chlorpyrifos-methyl, fenitrothion, chlorpyrifos, triphenyl phosphate, EPN, phosalone, pyrazophos, and pyraclofos (Table 4.4). The mean concentrations ranged from 0 to 1.91ppb, with a total mean concentration of 0.0011405 μ g/kg, showing a 32.693% increase compared to the raw samples (7.200 μ g/kg). There was however, no significant difference ($p>0.05$) in the concentrations of OPPs between the raw and boiled samples. The highest concentrations were recorded for Fenitrothion (1.91pbb) followed by Phosalone (1.58pbb) and 1,3, dimethyl 2-nitrobenzene (1.02pbb) while compounds like Pyrazophos, Azinphos ethyl, Quinalphos, pirimiphos methyl and Isazophos.

Table 4.3: Mean concentration of Organophosphate Pesticides found in Raw Prawn Samples (*Macrobrachium vollehoveni*)

Target Compounds	Mean \pm SD	SE	%	Min	Max
1,3-dimethyl-2-nitrobenzophosphorothioate (DMN)	0 0.185	0	0	0	0
Diazinon	± 0.262 0.135 \pm	0.185	2.569	0	0.37
Isazophos	0.191 0.395 \pm	0.135	1.875	0	0.27
Chloropyrifos-methyl	0.559	0.395	5.486	0	0.79
Phosphorothioic acid, S-(1,3,5-trimethyl-4-isopropylphenyl)-, methyl ester (Pirimiphos Methyl)	1.35 \pm 1.372	0.97	18.75	0.38	2.32
Fenitrothion	0	0	0	0	0
Pirimiphos Ethyl	1.695 \pm 0.318	0.225	23.542	1.47	1.92
Quinalphos	0.35 \pm 0.495 0.395 \pm	0.35	4.861	0	0.7
Chlorpyrifos	0.148	0.105	5.486	0.29	0.5
Ethyl paranitrophenyl phenylphosphonothioate (EPN)	0.96 \pm 1.358 0.765 \pm	0.96	13.333	0	1.92
Phosalone	1.082	0.765	10.625	0	1.53
Pyrazophos	0.68 \pm 0.962	0.68	9.444	0	1.36
Azinphos-ethyl	0.29 \pm 0.410 1.395 \pm	0.29	4.028	0	0.58
Pyraclufos	1.464 8.595 \pm	1.035	19.375	0.36	2.43
Total	2.687		100		

Table 4.4: Mean concentration of Organophosphate Pesticides found in Boiled Prawn**Samples (*Macrobrachium vollehoveni*)**

Target Compounds	Mean \pm SD	SE	%	Min	Max
1,3-dimethyl-2-nitrobenzothiazole	1.02 \pm 0.721	0.721	8.94	0	0
Diazinon	0.24 \pm 0.170	0.170	2.104	0.24	0.24
Isazophos	0 \pm 0.191	0.191	0	0	0
Chloropyrifos-methyl	0.82 \pm 0.212	0.212	7.190	0.82	0.82
Pirimiphos Methyl	0	0	0	0	0
Fenitrothion	1.91 \pm 0.226	0.226	16.747	1.91	1.91
Pirimiphos Ethyl	0.72 \pm 0.509	0.509	6.313	0.72	0.72
Quinalphos	0 \pm 0.495	0.495	0	0	0
Chlorpyrifos	5.97 \pm 2.390	2.390	52.345	5.97	5.97
Ethyl paranitrophenyl phenylphosphonothioate (EPN)	0.21 \pm 0.148	0.148	1.841	0.21	0.21
Phosalone	1.58 \pm 0.035	0.035	13.854	1.58	1.58
Pyrazophos	0	0	0	0	0
Azinphos-ethyl	0	0	0	0	0
Pyraclofos	0.11 \pm 1.640	1.640	0.964	0.11	0.11
Total	11.405 \pm 1.662		100		

4.5 Human Health Risk Assessment of Pesticide Concentrations in Raw and Boiled prawn (*Macrobrachium vollehoveni*) samples

The estimated daily intake (EDI), hazard quotients (HQs) and hazard index (His) of pesticide residues in the raw prawn tissues are presented in Tables 4.5 and 4.6.

EDI values for the OCPs ranged from 0.000000 to 0.000016 (Table 4.5). The hazard quotients (HQs) and hazard index (HIs) values for OCPs in prawn samples for the estimated non-carcinogenic and carcinogenic health risk were below 1 (Table 4.5).

EDI values for the OPPs ranged from 0 to 7.673E-06 (Table 4.6). The hazard quotients (HQs) and hazard index (HIs) values for OPPs in prawn samples for the estimated non-carcinogenic and carcinogenic health risk were below 1 (Table 4.6).

For the boiled samples, the estimated daily intake (EDI), hazard quotients (HQs) and hazard index (His) of pesticide residues in the raw prawn tissues are presented in Tables 4.7 and 4.8.

EDI values for the OCPs ranged from 0.000000 to 0.000033 (Table 4.7). The hazard quotients (HQs) and hazard index (HIs) values for OCPs in prawn samples for the estimated non-carcinogenic and carcinogenic health risk were below 1 (Table 4.7).

EDI values for the OPPs ranged from 0 to 0.000032835 (Table 4.8). The hazard quotients (HQs) and hazard index (HIs) values for OPPs in prawn samples for the estimated non-carcinogenic and carcinogenic health risk were below 1 (Table 4.8).

Table 4.5: Estimated Daily Intake, hazard quotients (HQs) and hazard index (HIs) of OCPs in the raw prawn samples

OCPs	MEAN			EDI	RfD	HQ(non-	SF	HQ
	(Cp)	IFR	BW			carcinogenic)		(Carcinogenic)
α - HCH	0.0009	0.3300	60.00	0.000004	0.008	0.0006	6.3	0.000028
β -HCH	0.0004	0.3300	60.00	0.000002	NA	NA	NA	NA
γ - HCH (LINDANE)	0.0020	0.3300	60.00	0.000010	0.0003	0.0317	1.3	0.000012
Heptachlor	0.0010	0.3300	60.00	0.000007	0.0005	0.0149	4.5	0.000034
δ -HCH	0.0008	0.3300	60.00	0.000004	NA	NA	NA	NA
Aldrin	0.0010	0.3300	60.00	0.000006	0.00003	0.1843	17	0.000094
Heptachlor Epoxide	0.0000	0.3300	60.00	0.000000	0.000013	0	9.1	0.000000
Gamma- Chlordane	0.0014	0.3300	60.00	0.000008	NA	NA	NA	NA
Alpha- Chlordane	0.0004	0.3300	60.00	0.000002	NA	NA	NA	NA
Endosulfan I	0.0029	0.3300	60.00	0.000016	0.006	0.0027	NA	NA
P,p'-DDE	0.0013	0.3300	60.00	0.000007	NA	NA	0.34	0.000002
Dieldrin	0.0024	0.3300	60.00	0.000013	0.00005	0.2585	16	0.000207
Endrin	0.0026	0.3300	60.00	0.000014	0.0003	0.0479	NA	NA
P,P'-DDD	0.0030	0.3300	60.00	0.000016	NA	NA	0.24	0.000004
Endsulfan II	0.0022	0.3300	60.00	0.000012	0.006	0.0020	NA	NA
P,P'-DDT	0.0019	0.3300	60.00	0.000011	0.0005	0.0210	0.32	0.000003
Endrin aldehyde	0.0007	0.3300	60.00	0.000004	NA	NA	NA	NA
Endosulfan sulfate	0.0012	0.3300	60.00	0.000006	NA	NA	NA	NA
Methoxychlor	0.0001	0.3300	60.00	0.000000	0.005	0.000072	NA	NA
Endrin ketone	0.0023	0.3300	60.00	0.000013	NA	NA	NA	NA
					HI	0.563665		0.000384

Key: NA= Not Available

RfD = Reference Dose

Table 4.6: Estimated Daily Intake, hazard quotients (HQs) and hazard index (His) of OPPs in the raw prawn tissues.

OPPs	MEAN [©]	IFR	BW	EDI	RfD(ADI)	HQ	HQ	
						(Non-carcinogenic)	(Carcinogenic)	SF
Diazinon	0.0002	0.33	60	1.018E-06	0.0009	0.0011	NA	NA
Isazophos	0.0001	0.33	60	7.425E-07	NA	NA	NA	NA
Chlorpyrifos-methyl	0.0004	0.33	60	2.173E-06	0.01	0.0002	NA	NA
Pirimiphos Methyl	0.0013	0.33	60	0.00001	NA	NA	NA	NA
Fenitrothion	0	0.33	60	0	NA	NA	NA	NA
Pirimiphos Ethyl	0.0017	0.33	60	9.323E-06	NA	NA	NA	NA
Quinalphos	0.0004	0.33	60	0.000002	NA	NA	NA	NA
Chlorpyrifos	0.0004	0.33	60	2.173E-06	3E-03	NA	NA	NA
Ethyl paranitrophenyl phenylphosphonothioate (EPN)	0.0010	0.33	60	0.00001	NA	NA	NA	NA
Phosalone	0.0008	0.33	60	4.208E-06	NA	NA	NA	NA
Pyrazophos	0.0007	0.33	60	0.000004	NA	NA	NA	NA
Azinphos-ethyl	0.0003	0.33	60	0.000002	NA	NA	NA	NA
Pyraclufos	0.0014	0.33	60	7.673E-06	NA	NA	NA	NA
					HI	0.001		

Key: NA= Not Available

RfD = Reference Dose

Table 4.7: Estimated Daily Intake, hazard quotients (HQs) and hazard index (His) of OCPs in the boiled prawn samples

OCPs	MEAN					HQ(Non-	SF	HQ
	(Cp)	IFR	BW	EDI	RfD	carcinogenic)		(Carcinogenic)
α – HCH	0.0000	0.330	60.000	0.000000	0.008000	0.000000	6.300000	0.000000
β -HCH	0.0000	0.330	60.000	0.000000	NA	NA	NA	NA
γ - HCH (LINDANE)	0.0001	0.330	60.000	0.000001	0.00030	0.002	1.300000	0.000001
Heptachlor	0.0008	0.330	60.000	0.000004	0.00050	0.009	4.500000	0.000020
δ -HCH	0.0007	0.330	60.000	0.000004	NA	NA	NA	NA
Aldrin	0.0007	0.330	60.000	0.000004	0.00003	0.134	17.000000	0.000068
Heptachlor Epoxide	0.0013	0.330	60.000	0.000007	0.00001	0.556	9.100000	0.000066
Gamma- Chlordane	0.0023	0.330	60.000	0.000013	NA	NA	NA	NA
Alpha- Chlordane	0.0019	0.330	60.000	0.000010	NA	NA	NA	NA
Endosulfan I	0.0015	0.330	60.000	0.000008	0.00600	0.001	NA	NA
P,p'-DDE	0.0012	0.330	60.000	0.000007	NA	NA	0.340	0.000002
Dieldrin	0.0008	0.330	60.000	0.000004	0.00005	0.087	16.000	0.000070
Endrin	0.0006	0.330	60.000	0.000003	0.00030	0.011	NA	NA
P,P'-DDD	0.0059	0.330	60.000	0.000033	NA	NA	0.240	0.000008
Endsulfan II	0.0016	0.330	60.000	0.000009	0.00600	0.001	NA	NA
P,P'-DDT	0.0000	0.330	60.000	0.000000	0.00050	0.000	0.320	0.000000
Endrin aldehyde	0.0004	0.330	60.000	0.000002	NA	NA	NA	NA
Endosulfan sulfate	0.0009	0.330	60.000	0.000005	NA	NA	NA	NA
Methoxychlor	0.0015	0.330	60.000	0.000008	0.00500	0.002	NA	NA
Endrin ketone	0.001540	0.330	60.000	0.000008	NA	NA	NA	NA

Key: NA= Not Available

RfD = Reference Dose

Table 4.8: Estimated Daily Intake, hazard quotients (HQs) and hazard index (HIs) of OPPs in the boiled prawn tissues.

OPPs	MEAN [©]	IFR	BW	EDI	RfD(ADI)	HQ	
						(Non-carcinogenic)	SF (Carcinogenic)
Diazinon	0.0002	0.330	60	0.000001	0.0009	0.001	NA NA
Isazophos	0	0.330	60	0	NA	NA	NA NA
Chlorpyrifos-methyl	0.0008	0.330	60	0.000005	0.01	0.0005	NA NA
Pirimiphos Methyl	0	0.330	60	0	NA	NA	NA NA
Fenitrothion	0.002	0.330	60	0.00001	NA	NA	NA NA
Pirimiphos Ethyl	0.0007	0.330	60	0.000004	NA	NA	NA NA
Quinalphos	0	0.330	60	0	NA	NA	NA NA
Chlorpyrifos	0.006	0.330	60	0.00003	3E-03	NA	NA NA
Ethyl paranthrophenyl phenylphosphonothioate (EPN)	0.0002	0.330	60	0.000001	NA	NA	NA NA
Phosalone	0.002	0.330	60	0.000009	NA	NA	NA NA
Pyrazophos	0	0.330	60	0	NA	NA	NA NA
Azinphos-ethyl	0	0.330	60	0	NA	NA	NA NA
Pyraclufos	0.0001	0.330	60	0.0000006	NA	NA	NA NA
					HI	0.001917667	

Key: NA= Not Available

RfD = Reference Dose

CHAPTER FIVE

DISCUSSION

The present study assessed the effect of boiling on organochlorine (OCP) and organophosphate (OPP) pesticide residues in the African freshwater prawn (*Macrobrachium vollehovenii*) collected from Oba and Uselu Markets, Benin City, Edo State, Nigeria. Results revealed the presence of multiple pesticide residues in both raw and boiled prawn samples, highlighting ongoing environmental contamination of aquatic ecosystems.

5.1 Organochlorine Pesticide Residues

The detection of organochlorine pesticide residues such as HCH isomers, DDT metabolites, endosulfan, and chlordane derivatives in both raw and boiled samples indicate the persistence of these compounds in the aquatic environment. Despite restrictions and bans on several OCPs in Nigeria, their detection suggests residual contamination from historical use or illegal application in nearby agricultural areas (Adeyemi *et al.*, 2008; Tongo *et al.*, 2017). The observed 34.3% reduction in total OCP concentration after boiling (from 2.345 µg/kg to 1.540 µg/kg) implies partial degradation or volatilisation of some compounds due to heat exposure. Similar reductions have been reported in studies where boiling and frying reduced OCP residues in fish and shrimp tissues by 20–60%, depending on compound stability (Darko and Acquah, 2008; Akinneye *et al.*, 2018). However, the persistence of compounds such as Endosulfan II and Alpha-Chlordane after boiling demonstrates their high thermal stability and lipophilicity, which promote retention in fatty tissues even after cooking (Akoto *et al.*, 2016).

5.2 Organophosphate Pesticide Residues

In contrast to OCPs, organophosphate pesticide concentrations increased by 58.4% following boiling (from 7.200 $\mu\text{g}/\text{kg}$ to 11.405 $\mu\text{g}/\text{kg}$). While OPPs are generally more thermolabile than OCPs, some, such as chlorpyrifos and phosalone, exhibit high chemical stability under moderate heating conditions. This may explain their elevated concentrations in boiled samples. Comparable trends have been observed in other seafood studies where cooking reduced water content and enhanced the apparent concentration of lipid-soluble pesticide residues (Ali *et al.*, 2019).

5.3 Health Risk Implications

The estimated daily intake (EDI) values for all detected pesticides in raw and boiled samples were below their respective acceptable daily intake (ADI) limits, indicating a low likelihood of immediate health risk from prawn consumption. Similarly, hazard quotient (HQ) and hazard index (HI) values were less than one (<1), signifying minimal non-carcinogenic and carcinogenic risks. These findings are consistent with previous reports on fish and crustaceans from Nigerian aquatic systems, where dietary exposure to pesticide residues was found to be within safe margins (Ogbeide *et al.*, 2015; Tongo *et al.*, 2017). Nonetheless, the detection of persistent and bioaccumulative compounds such as DDT and lindane remains a cause for concern, as continuous exposure through seafood consumption may contribute to chronic health effects, including endocrine disruption, reproductive toxicity, and neurotoxicity (Olisah *et al.*, 2021).

5.4 Environmental and Food Safety Considerations

The presence of both OCPs and OPPs in *M. vollehovenii* reflects the contamination of local aquatic ecosystems, likely resulting from agricultural runoff, indiscriminate pesticide use, and

improper waste disposal. These findings align with earlier studies documenting pesticide residues in fish and sediments from Nigerian inland waters (Ezemonye *et al.*, 2008; Tongo *et al.*, 2014). The persistence of these residues in edible aquatic organisms poses a dual challenge for environmental management and food safety regulation. Although boiling, a common domestic cooking method partially reduced some pesticide residues, it did not eliminate them. This suggests that thermal processing alone may be insufficient for residue mitigation.

Continuous monitoring of aquatic food sources and stricter enforcement of pesticide regulations are therefore essential to minimize human exposure. The adoption of integrated pest management (IPM) practices, public education on pesticide hazards, and strengthened residue surveillance in seafood are recommended for ensuring food safety and protecting public health (Zain *et al.*, 2019).

CONCLUSION AND RECOMMENDATIONS

This study evaluated the concentrations of organochlorine and organophosphate pesticide residues in *Macrobrachium vollehovenii* obtained from Oba and Uselu Markets, Benin City, Edo State, Nigeria, and further assessed the impact of boiling on these residues. The detection of multiple pesticide residues in both raw and boiled samples demonstrate the persistence of agricultural contaminants in aquatic food resources. While boiling reduced the levels of some organochlorine compounds, it did not eliminate them entirely, and in some cases, the concentrations of certain organophosphates increased due to moisture loss and concentration effects.

Although the estimated daily intake (EDI), hazard quotient (HQ), and hazard index (HI) values were below acceptable limits, indicating minimal immediate health risks, the continuous ingestion of contaminated seafood over time may contribute to cumulative toxic exposure. The presence of persistent compounds such as DDT and lindane underscores the need for improved environmental control measures and regulatory enforcement on pesticide use in agricultural activities.

This study therefore highlights that while common household cooking practices like boiling can reduce certain pesticide residues, they are not wholly effective in eliminating chemical contaminants. Hence, the findings provide critical insights for public health authorities, food safety regulators, and consumers on the importance of pre-market monitoring and responsible pesticide application.

To safeguard public health and ensure the safety of aquatic food resources, regular monitoring and surveillance of pesticide residues in aquatic foods, particularly prawns and fish should be

conducted by environmental and food safety agencies. This will help ensure that residue levels remain within internationally accepted standards such as those set by the FAO/WHO Codex Alimentarius and the European Union Maximum Residue Limits (MRLs). Effective regulation and enforcement are essential to strengthen their oversight of pesticide use, with strict enforcement of existing bans and controls on restricted compounds to minimize further contamination of aquatic ecosystems. Public awareness and education should also be prioritized, farmers, fishers, and traders need to be sensitized on the safe and judicious use of pesticides, the dangers of over-application, and the long-term benefits of adopting Integrated Pest Management (IPM) strategies, which emphasize environmentally sustainable pest control.

There is also a need for continued research to explore how different cooking methods, such as frying, grilling, or smoking, affect pesticide degradation and residue retention in seafood. Such studies would provide deeper insights into the thermal stability of various pesticide compounds and their potential health implications.

REFERENCES

- Adeyemi, D., Ukpo, G., Anyakora, C. and Unyimadu, J.P. (2008) 'Organochlorine pesticide residues in fish samples from Lagos Lagoon, Nigeria', *American Journal of Environmental Sciences*, **4**(6), pp. 649-653
- Akinneye, J.O., Adeleye, O.A., Adesina, F.P. and Akinyemi, M.I., 2018. Assessment of pesticide residue on cocoa beans in Ondo State, Nigeria. *Brazilian Journal of Biological Sciences*, **5**(10), pp.577-588.
- Akinsanya, B., Alani, R., Ukwa, U. D., Bamidele, F. and Saliu, J. K. (2015). Bioaccumulation and distribution of organochlorine residues across the food web in Lagos Lagoon, Nigeria. *African Journal of Aquatic Science*, **40**(4), 403 - 408.
- Akoto, O., Azuure, A.A. and Adotey, K.D. Pesticide residues in water, sediment and fish from Tono Reservoir and their health risk implications. *SpringerPlus* **5**, 1849 (2016).
- Ali, H., Khan, E. and Ilahi, I., 2019. Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, **2019** (1), p.6730305.
- Arisekar, U., Shakila, R.J., Shalini, R., Jeyasekaran, G. and Padmavathy, P., 2022. Effect of household culinary processes on organochlorine pesticide residues (OCPs) in the seafood (*Penaeus vannamei*) and its associated human health risk assessment: Our vision and future scope. *Chemosphere*, **297**, p.134075.

- Arnot, J. A. and Gobas, F. A. P. C., 2006. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environmental Reviews*, **14**(4), pp.257–297.
- Asiru, R.A. and Fafioye, O.O., 2018. Proximate composition of the giant river prawn, *Macrobrachium vollehovonii* from River Osun, Southwestern Nigeria. *Journal of Fisheries and Livestock Production*, **6**, p.285.
- Bradberry, S.M., Cage, S.A., Proudfoot, A.T. and Vale, J.A., 2005. Poisoning due to pyrethroids. *Toxicological Reviews*, **24**(2), pp.93–106.
- Burrige, L., Weis, J.S., Cabello, F., Pizarro, J. and Bostick, K., 2010. Chemical use in salmon aquaculture: A review of current practices and possible environmental effects. *Aquaculture*, **306**(1–4), pp.7–23.
- Carvalho, F.P., 2017. Pesticides, environment, and food safety. *Food and Energy Security*, **6**(2), pp.48–60.
- Casida, J.E., 2017. Pest toxicology: the primary mechanisms of pesticide action. *Chemical Research in Toxicology*, **30**(1), pp.94–103.
- Costa, L.G., 2006. Current issues in organophosphate toxicology. *Clinica Chimica Acta*, **366**(1–2), pp.1–13.
- Darko, G. and Acquah, S.O., 2008. Levels of organochlorine pesticides residues in dairy products in Kumasi, Ghana. *Chemosphere*, **71**(2), pp.294–298.

- Darko, G., Akoto, O. and Oppong, C., 2013. Persistent organochlorine pesticide residues in fish species from the Densu River Basin, Ghana. *Bulletin of Environmental Contamination and Toxicology*, **90**(4), pp.421–426.
- Ecobichon, D.J., 2001. *Pesticide use in developing countries*. *Toxicology*, **160**(1–3), pp.27–33.
- Edjere, O., Ukpebor, J. and Okieimen, F. E., 2020. Hazard Quotient and Bioaccumulation Assessment of 26 Organochlorine Pesticides in Water, Sediment and Fish (*Tilapia zilli*) Warri River, Niger Delta Region - Southern Nigeria. *Asian Journal of Applied Chemistry Research*, **6**(1), pp.21–33.
- Egbuna, C., Parmar, V.K., Jeevanandam, J., Ezzat, S.M., Patrick Iwuanyanwu, K.C., Adetunji, C.O., Khan, J., Onyeike, E.N., Uche, C.Z., Akram, M., Ibrahim, M.S., El Mahdy, N.M., Awuchi, C.G., Saravanan, K., Tijjani, H., Odoh, U.E., Messaoudi, M., Ifemeje, J.C., Olisah, M.C., Ezeofor, N.J., and Ibeabuchi, C.G. (2021) ‘Toxicity of nanoparticles in biomedical application: Nanotoxicology’, *Journal of Toxicology*, 2021, pp 9954443
- Ezemonye, L. I., Ogbeide, O. S., Tongo, I. and Enuneku, A. A., 2015. Pesticide contaminants in *Clarias gariepinus* and *Tilapia zilli* from three rivers in Edo State, Nigeria; implications for human exposure. *Food Safety and Risk*, **2**(3).
- Ezemonye, Lawrence I., Ikpesu, T. and Ilechie, I. (2008) ‘Distribution of diazinon in water, sediment and fish from Warri River, Niger Delta, Nigeria’, *Jordan Journal of Biological Sciences*, **1**, pp. 77–83.
- FAO (Food and Agriculture Organization of the United Nations), 2020. *Pesticide use and risk reduction*.

- Fenner, K., Canonica, S., Wackett, L. P. and Elsner, M. (2013) 'Evaluating pesticide degradation in the environment: blind spots and emerging opportunities', *Science*, **341**(6147), pp. 752–758.
- Gavrilescu, M., 2005. Fate of pesticides in the environment and its bioremediation. *Engineering in Life Sciences*, **5**(6), pp.497–526.
- Gobas, F. A. P. C., Morrison, H. A. and Haffner, G. D., 1999. Biochemical cycling and bioaccumulation of hydrophobic organic contaminants in aquatic food webs. *Environmental Science & Technology*, **33**(3), pp.133–141.
- Hu, R., Huang, X., Huang, J., Li, Y., Zhang, C., Yin, Y., Chen, Z., Jin, Y., Cai, J. & Cui, F. (2015) 'Long- and Short-Term Health Effects of Pesticide Exposure: A Cohort Study from China',
- Ikpeni, S., Ejiogu, N. C. et al. (2014) 'Photodegradation and hydrolysis of Chlorpyrifos in aqueous systems', *Nigerian Journal of Technology*, **33**(4), pp. 553-558.
- Islam, M.A., Amin, S.M.N., Rahman, M.A., Juraimi, A.S., Uddin, M.K., Brown, C.L. and Arshad, A., 2022. Chronic effects of organic pesticides on the aquatic environment and human health: A review. Islam, M.A., Amin, S.M.N., Rahman, M.A., Juraimi, A.S., Uddin, M.K., Brown, C.L. and Arshad, A., 2022. Chronic effects of organic pesticides on the aquatic environment and human health: A review. *Environmental Nanotechnology, Monitoring & Management*, **18** (100740).
- Jaga, K. and Dharmani, C., 2003. Sources of exposure to and public health implications of organophosphate pesticides. *Rev. Panam. Salud Pública*, **14**(3), pp.171–185.

- 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), pp.90–100.
- Saikia, S., Dutta, R. and Tiwari, S., 2022. Organophosphate pesticide residues in environmental and biological matrices: occurrence, distribution and potential remedial approaches. *Environmental Chemistry and Ecotoxicology*, **5**, pp.9–23.
- Köck-Schulmeyer, M., Villagrasa, M., López de Alda, M., Céspedes-Sánchez, R., Ventura, F. and Barceló, D., 2013. Occurrence and behavior of pesticides in wastewater treatment plants and their environmental impact. *Science of The Total Environment*, **458–460**, pp.466–476.
- Maia, M.L., Sousa, S., Correia-Sá, M.L., Delerue-Matos, C., Calhau, C. and Domingues, V.F., 2020. Organochlorine pesticides, brominated flame retardants, synthetic musks and polycyclic aromatic hydrocarbons in shrimps. An overview of occurrence and its implication on human exposure. *Heliyon*, **6**(9).
- Marrs, T.C., 2012. Organophosphate and carbamate insecticide poisoning. In: Vale, J.A. and Marrs, T.C., eds. *Chemical Toxicology and Clinical Toxicology of Organophosphates and Carbamates*. London: Elsevier, pp.47–65.
- Meli, S.N., Ngueguim, J.R., Nguemo, H. et al., 2023. Multi-residue analysis of pesticides in freshwater fish from the Menoua River, Cameroon. *Environmental Monitoring and Assessment*, **195**(6), pp.1–11.
- Moses, E.A., Akpan, D., Shaibu, S.E., Usen, O.O. and Akaninyene, A.O., 2022. Risk assessment of pesticide residues in fish samples from Nwaniba River, Akwa Ibom state, Nigeria. *World Journal of Applied Science & Technology*, **14**(2), pp.65–72.

- Mshelia, J.U., Jatau, A.M., Zakari, M. and Usman, A., 2022. Levels of Organochlorine Pesticide Residues in Tissues of Fish Samples from River Benue, Vinikilang, Adamawa State, Nigeria. *ChemSearch Journal*, **13**(1), pp.18–25.
- Muir, D. C. G. and Howard, P. H., 2006. Are there other persistent organic pollutants? A challenge for environmental chemists. *Environmental Science & Technology*, **40**(23), pp.7157–7166.
- Ogah, C. O. et al. (2017) ‘Effect of heat on pesticide residue content of beans samples from markets in Lagos, Nigeria’, *Longdom Proceedings*, 86% of samples showed reduction; organophosphates reduction 24-100%, carbamates 20-100%, organochlorines 9-32%.
- Ogah, C. O., Coker, H. B. & Adepoju-Bello, A. A. (2011) ‘Organophosphate and Carbamate Pesticide Residues in Beans from Markets in Lagos State, Nigeria’, *Journal of Innovative Research in Engineering and Sciences*, **2**(1).
- Ogbeide, O.S., Tongo, I. and Ezemonye, L.I., 2015. Assessment of organochlorine pesticide residue levels in water, sediment and fish samples from Owan River, Edo State, Nigeria. *Environmental Monitoring and Assessment*, **187**(2), pp.1–9.
- Ojo, J. (2016). Pesticide Use and Health in Nigeria. *Ife Journal of Sciences*. **18**(4): 981-991
- Olisah, C., Adams, J.B. and Rubidge, G., 2021. The state of persistent organic pollutants in South African estuaries: A review of environmental exposure and sources. *Ecotoxicology and Environmental Safety*, **219**, 112316
- Orou-Seko, A., Chirawurah, D., Ndago, J. A., Nkansah-Baido, M., Pwatirah, D., Kolekang, A. S., and Adokiya, M. N. (2024) ‘Farmers’ pesticide use and knowledge of aquatic ecosystem

contamination with its perceived health risk from contaminated fish consumption in northern Ghana', *Scientific African*, **26**, e02351.

Rand, G. M., Wells, P. G. and McCarty, L. S., 1995. *Introduction to Aquatic Toxicology*. Washington, DC: Taylor and Francis.

Rico, A., Satapornvanit, K., Haque, M.M., Min, J., Nguyen, P.T., Telfer, T.C. and van den Brink, P.J., 2012. Use of chemicals and biological products in Asian aquaculture and their potential environmental risks: a critical review. *Reviews in Aquaculture*, **4**(2), pp.75–93.

Sarkar, D., Luo, Y., Sun, G.X. 2022. Quantification of insecticides in commercial seafood sold in East Asian markets: risk assessment for consumers. *Environmental Science and Pollution Research*, **30**, pp.34585–34597.

Schulz, R., 2004. Field studies on exposure, effects, and risk mitigation of aquatic nonpoint-source insecticide pollution: a review. *Journal of Environmental Quality*, **33**(2), pp.419–448.

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

Tongo, I., Ezemonye, L. and Akpeh, K., 2017. Levels, distribution and characterization of Polycyclic Aromatic Hydrocarbons (PAHs) in Ovia River, Southern Nigeria. *Journal of Environmental Chemical Engineering*, **5**(1), pp.504–512.

Tongo, I., Ezemonye, Lawrence I., Nupe, P. and Ogbomida, E. (2014) 'Levels, distribution and human health risk assessment of organochlorine pesticide residues in surface water from Ikpoba River, Nigeria', *Nigerian Journal of Scientific Research*, **13**, pp. 26–34.

- Ukpebor, J. E., Ikpeni, S., Ejiogu, N. C. & Ukpebor, E. E. (2014) 'Photodegradation and Hydrolysis of Chlorpyrifos in Aqueous Systems', *Nigerian Journal of Technology*, **33**(4), pp. 553–558.
- Usifoh, C.O., Nuntah, J.N., Abolagba, O.J., Igene, J.O., Usifoh, S.F. and Omoti, C.E., 2019. Incidence of organochlorine pesticide residues in smoke-dried fish species marketed in South-West Nigeria. *Journal of Pharmacy & Bioresources*, **16**(1), pp.9–15.
- Van den Berg, H., 2009. Global status of DDT and its alternatives for use in vector control to prevent disease. *Environmental Health Perspectives*, **117**(11), pp.1656–1663.
- Waqas, W., Yuan, Y., Ali, S., Zhang, M., Shafiq, M., Ali, W., Chen, Y., Xiang, Z., Chen, R., Ikhwanuddin, M. and Ma, H., 2024. Toxic effects of heavy metals on crustaceans and associated health risks in humans: a review. *Environmental Chemistry Letters*, **22**(3), pp.1391-1411.
- Ware, G.W. and Whitacre, D.M., 2004. *The Pesticide Book*. 6th ed. Willoughby, OH: MeisterPro Information Resources.
- Zain, S.M.S.M., Azmi, W.N.F.W., Veloo, Y. and Shaharudin, R. (2019) 'Formaldehyde exposure, health symptoms and risk assessment among hospital workers in Malaysia', *Journal of Environmental Protection*, **10**(6), pp. 732–743.