ASSESSMENT OF PARASITIC CONTAMINATION IN FISH PONDS IN BENIN CITY AND THEIR PUBLIC HEALTH IMPLICATIONS

BY

GEORGE ERINYANGA SOLOMON

BMS2001162

DEPARTMENT OF MEDICAL LABORATORY SCIENCE

SCHOOL OF BASIC MEDICAL SCIENCES

COLLEGE OF MEDICAL SCIENCES

UNIVERSITY OF BENIN, NIGERIA

SEPTEMBER, 2025

ASSESSMENT OF PARASITIC CONTAMINATION IN FISH PONDS IN BENIN CITY AND THEIR PUBLIC HEALTH IMPLICATIONS

BY

GEORGE ERINYANGA SOLOMON

BMS2001162

A PROJECT SUBMITTED TO THE DEPARTMENT OF MEDICAL LABORATORY SCIENCE, SCHOOL OF BASIC MEDICAL SCIENCES, COLLEGE OF MEDICAL SCIENCES, UNIVERSITY OF BENIN, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE IN MEDICAL LABORATORY SCIENCE

SUPERVISED BY DR. (MRS.) Z. OMORUYI

SEPTEMBER, 2025

CERTIFICATION

We the undersigned certify that this research work was carried out by **GEORGE ERINYANGA SOLOMON** in the Department of Medical Laboratory Science, School of Basic Medical Science, University of Benin, Benin City in partial fulfillment of the requirements for the award of Bachelor of Science in Medical Laboratory Science.

______________________ ______________________

DR. (MRS.) Z. OMORUYI **DATE**

(Project Supervisor)

______________________ ______________________

DR. (MRS.) Z. OMORUYI **DATE**

(Head of Department)

______________________ ______________________

Prof. Omoruyi Pius Omosigho **DATE**

External Examiner

DEDICATION

This project is dedicated to Almighty God.

ACKNOWLEDGEMENT

First and foremost, I give all thanks to God Almighty for His strength, wisdom, and grace throughout the course of this project. Without Him, this work would not have been possible.

My heartfelt appreciation goes to Dr. Mrs. Zainab Omoruyi (my project supervisor and Head of Department, Medical Laboratory Science – UNIBEN) for her invaluable guidance and consistent support during every phase of this research. And to all my lecturers, thank you.

I am deeply grateful to my dearest mother and the entire members of my family (the family of Rev. S. G. Udofah) for their unwavering love, encouragement, and moral support throughout this journey.

I also want to sincerely appreciate Fynecountry Donald, Chioma Nwaribe, Endurance Egure, Peter Obasi and many others who contributed in one way or another. Your support, whether big or small, meant a lot and helped me reach this milestone.

Thank you very much.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Parasitic contamination in aquaculture systems poses significant threats to both fish health and public safety, particularly in developing countries where food security depends heavily on freshwater fish production. This study aimed to assess the prevalence of parasitic contamination in fish ponds across Benin City, Edo State, Nigeria, and evaluate the associated public health implications. A total of 50 water samples were collected from fish ponds across three local government areas: Ikpoba Okha (n=17), Ovia North East (n=16), and Oredo (n=17). Water samples were analyzed using direct microscopy, flotation, and sedimentation techniques to identify parasitic stages including eggs, larvae, and cysts. Key findings revealed a high overall prevalence of parasitic contamination at 54.0% across all examined ponds. *Ascaris lumbricoides* ova were the most frequently detected parasites (44.0%), followed by *Strongyloides stercoralis* larvae (30.0%), *Cryptosporidium parvum* cysts (18.0%), and *Schistosoma haematobium* ova (8.0%). The highest contamination rates were observed in Ikpoba Okha (64.7%), followed by Oredo (52.9%) and Ovia North East (43.8%), though statistical analysis revealed no significant association between local government areas and contamination prevalence ($p = 0.480$). The majority of ponds (26%) harbored single parasites, while 4% contained four different parasitic species. The identification of zoonotic parasites with confirmed human health implications underscores the urgent need for improved aquaculture management practices, enhanced biosecurity measures, and comprehensive surveillance programs. These findings emphasize the necessity for integrated public health initiatives aimed at reducing parasitic transmission risks through improved pond management, proper fish processing techniques, and consumer education programs to safeguard community health in Benin City.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

Aquaculture, the farming of fish and other aquatic organisms, is gaining increasing prominence in Nigeria due to the country's growing demand for food, protein sources, and income-generating activities (Jegede *et al*., 2015). However, the sustainability of this industry is jeopardized by various pathogenic organisms that pose significant threats to both fish health and public health. Parasitic infections are among the notable challenges in aquaculture, leading to substantial economic losses from mortality, stunted growth, and reduced market value of affected fish (Bhowmik *et al*., 2020).

In Benin City, the aquaculture sector has experienced growth with the establishment of numerous fish farms. While these farms contribute significantly to the local economy, concerns have arisen regarding the potential adverse effects of parasitic contamination in fish ponds, including the risk of zoonotic disease transmission to humans (Challaton *et al*., 2022). Previous studies have shown that fish reared in contaminated water are susceptible to various parasites that can negatively impact their histological and physiological functionality, ultimately creating health risks for consumers (Ramakant *et al*., 2024).

Research indicates that improper management of fish ponds can result in the accumulation of pathogens, such as protozoa and helminthic parasites, in the water, which can be detrimental to the health of both aquatic organisms and humans consuming the fish (Challaton *et al*., 2022). Contaminated fish can serve as vectors for pathogens, leading to serious implications for food safety and public health. Moreover, while much of the current literature focuses on fish management practices, water quality, and the implications of chemical contaminants in aquaculture, a comprehensive understanding of parasitic infections in fish farming remains underexplored, especially in Nigeria (Jegede *et al*., 2015; (Marskole *et al*., 2016).

Considering the rising interest in aquaculture and its public health implications, this study aims to assess the level of parasitic contamination present in fish ponds in Benin City, evaluate its implications for public health, and seek possible management solutions to mitigate these risks.

1.2 Statement of the Problem

The potential for zoonotic transmission of parasites from contaminated fish to humans is a pressing public health concern that has not been adequately addressed in many regions, including Benin City. Parasitic infestations in fish can arise from various sources, including poor water quality, unsanitary pond management practices, and contamination from agricultural runoff and urban sewage (Bhowmik *et al*., 2020; Ramakant *et al*., 2024). Some common parasites that infect fish include *Giardia lambia*, *Cryptosporidium parvum*, *Diphyllobothrium latum*, and various trematodes that may persist in the aquaculture ecosystem. These parasites may not only threaten fish population dynamics and farm sustainability but also create substantial risks for consumers who may become infected through the consumption of undercooked or contaminated fish (Marskole *et al*., 2016; Challaton *et al*., 2022).

Furthermore, the likelihood of parasite increases significantly transmission through the food chain due to the traditional practices of fish handling and preparation in Nigeria. Despite these vulnerabilities, there is a scarcity of comprehensive studies investigating parasitic contamination in fish ponds within Benin City, as well as the subsequent public health implications. The focus of this project is to fill the existing knowledge gap and generate empirical evidence to inform stakeholders in the aquaculture industry about critical health risks associated with parasitic infestations.

1.3 Significance of the Study

The evaluation of parasitic contamination in fish ponds in Benin City is incredibly important for various interconnected aspects of public health, food security, and ecological balance. To start, fish serves as a vital protein source for the people of Nigeria, playing a key role in tackling nutritional deficiencies that are common in the area. However, the presence of parasites can pose serious health risks to consumers, potentially leading to zoonotic diseases that add to the existing public health challenges (Abidemi-Iromini and Adelegan, 2019). Understanding how much parasitic infestation is present in fish is crucial not only for ensuring food safety but also for crafting policies that safeguard public health.

This study is essential for informing local fish farmers, consumers, and health authorities on the potential health risks associated with parasitic infections in aquaculture. By providing solid data on the prevalence and types of parasites affecting fish populations, this research can help set guidelines for farming practices that reduce contamination risks and ultimately enhance the sustainability of local fish farming (Fakorede *et al*., 2020). Additionally, these assessments can lead to the creation of effective fish processing and cooking guidelines to minimize the transmission of parasites through the food chain, ensuring consumer safety (Abidemi-Iromini and Adelegan, 2019).

Beyond public health, the study also tackles ecological issues related to water quality and the health of local aquatic ecosystems. The presence of parasites in fish ponds can signal larger environmental problems, such as pollution and the effects of agricultural runoff, which can harm biodiversity and the overall health of aquatic habitats (Fakorede *et al*., 2020). By examining the connection between parasitic contamination and the ecological health of fish ponds, we can develop better management practices in both aquaculture and agriculture sectors, ensuring that both food production and environmental stewardship coexist harmoniously.

This study adds to the expanding research on aquaculture and public health in Nigeria, providing valuable data that reflects local realities and encourages further exploration to create better strategies for managing health risks linked to parasitic infestations in fish farming.

1.4 Justification of Study

The need for this study stems from the pressing public health issues tied to freshwater aquaculture in Nigeria. Fish is a crucial part of the Nigerian diet, playing a significant role in meeting the nation's protein needs and ensuring food security. However, the risk of parasitic contamination presents serious health threats to consumers, highlighting the importance of thorough assessments of zoonotic parasites in fish ponds. Previous studies have shown that parasitic contamination in fish can lead to severe gastrointestinal diseases in humans, making it clear that surveillance in aquaculture practices is essential (Ofoezie and Adebisi, 2020).

Moreover, research indicates that various pathogens, including protozoan and helminthic parasites, can flourish in aquaculture environments due to poor pond management and environmental factors like water quality (Alemayehu and Tesfaye, 2020). In Benin City, where artisanal fish farming is common and often lacks strict biosecurity measures, the risk of fish harboring harmful parasites is significantly heightened. These parasitic infections are frequently overlooked but can have serious implications for community health, especially among vulnerable groups like children and the elderly, who may have compromised immune systems (Nkeiruka and Obinna, 2021).

From an economic perspective, the aquaculture sector is crucial for many communities in Nigeria, providing livelihoods for numerous families. Identifying potential parasitic contamination can help protect fish farmers from the negative economic effects of zoonotic diseases and boost consumer confidence in aquaculture products. Research has pointed out that fish contaminated with parasites face marketability challenges, which can really hurt local economies that rely on aquaculture for their livelihoods (Akinwumi and Mofolorunsho, 2021). That's why it's so important to get a clear picture of how much parasitic contamination is happening in fish ponds. Not only will this help reduce health risks, but it can also enhance the industry's future by encouraging safer farming methods.

This study is set to fill a significant gap in the existing literature on parasitic infections in fish ponds in Nigeria. While there's plenty of research on integrated pest management for crops and livestock, the aquaculture sector hasn't received the same level of attention, particularly when it comes to parasitic pathogens (Nkeiruka and Obinna, 2021). By focusing on this relatively overlooked area, this research aims to provide crucial data that can shape policies on food safety, aquaculture management, and public health initiatives designed to minimize the risks of consuming infected fish.

By tackling these interconnected issues of public health, economic sustainability, and the promotion of responsible aquaculture practices, this research seeks to make a strong case for the ongoing need for monitoring, research, and public awareness about parasitism in fish farming in Benin City.

1.5 Aim of Study

The aim of this study is to assessment of parasitic contamination in fish ponds in fish ponds in Benin city and their public health implications.

1.6 Specific Objectives of the Study

The specific objectives of this study are:

1. to determine the prevalence of parasitic contamination of fish ponds in Benin City.
2. to identify the types of parasites that are affecting the fish in these ponds.
3. to assess the possible public health risks linked to eating fish

1.7 Research Questions

The following research questions will guide the research study:

1. What is the rate of parasitic contamination of fish pond in Benin City?
2. Which types of parasites are most commonly found in the infected fish ponds?
3. How do the parasites identified in fish ponds relate to potential zoonotic risks for humans?

1.8 Study Hypothesis

Hypothesis (H1): There is a notable difference in the prevalence of parasitic contamination among different fish ponds in Benin City.

Hypothesis (H2): Eating fish from contaminated ponds significantly raises the risk of parasitic infections in humans.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview of Aquaculture in Nigeria

Aquaculture in Nigeria has evolved significantly over the past five decades, transforming from traditional extensive systems to more intensive commercial operations. The sector gained momentum in the 1970s following government initiatives aimed at diversifying protein sources and reducing dependence on marine fisheries (Adewumi *et al*., 2020). Initially, aquaculture practices were characterized by simple pond systems utilizing indigenous species such as *Clarias gariepinus* (African catfish) and *Oreochromis niloticus* (Nile tilapia). The introduction of exotic species and improved breeding techniques in the 1990s marked a significant turning point in the industry's development (Olatunji-Akioye and Adeyemo, 2021).

The establishment of research institutions such as the Nigerian Institute for Oceanography and Marine Research (NIOMR) and various university aquaculture programs provided the technical foundation for sector growth. Government policies, including the National Special Programme for Food Security (NSPFS) launched in 2002, further accelerated aquaculture development by providing subsidies and technical support to fish farmers (Nwosu and Holzlöhner, 2019). Despite these advances, the sector continues to face infrastructural and technical challenges that limit its full potential.

2.1.2 Economic Importance and Contribution to Food Security

Aquaculture has become increasingly vital to Nigeria's economy and food security framework. The sector contributes approximately 15% to the country's total fish production, with an estimated annual output of 300,000 metric tons (FAO, 2022). This production significantly supplements the national protein supply, particularly in rural and peri-urban communities where alternative protein sources may be limited or expensive (Akintola and Brown, 2022).

The economic impact extends beyond direct fish production. The aquaculture value chain employs over 500,000 people across various activities including hatchery operations, feed production, pond construction, fish processing, and marketing (Nwokoye *et al*., 2021). Small-scale fish farming has particularly benefited rural communities by providing alternative livelihood opportunities and reducing poverty levels. Studies indicate that fish farming households have 23% higher income levels compared to non-farming households in rural Nigeria (Ogundipe and Fagbenro, 2023).

From a nutritional perspective, cultured fish provides essential amino acids, omega-3 fatty acids, and micronutrients crucial for addressing malnutrition, particularly among children and pregnant women. The accessibility and affordability of farmed fish compared to imported alternatives make it a critical component of food security strategies (Adeleke *et al*., 2021).

2.1.3 Major Aquaculture Practices and Species Cultured

Nigerian aquaculture predominantly utilizes earthen pond systems, which account for approximately 80% of production facilities (Ezeokoli and Chukwu, 2022). These systems range from extensive operations with minimal inputs to semi-intensive systems incorporating supplemental feeding and basic water management. The most commonly cultured species include *Clarias gariepinus*, which comprises 60% of total aquaculture production due to its hardy nature and market acceptability (Omobepade *et al*., 2023).

Oreochromis niloticus represents the second most important cultured species, particularly favored for its rapid growth rate and consumer preference in northern regions of Nigeria. Integrated aquaculture systems combining fish production with crop cultivation or livestock rearing have gained popularity, especially in areas with land constraints (Adebayo *et al*., 2020). Cage culture systems, though less common, are increasingly being adopted in natural water bodies and reservoirs, particularly for tilapia production.

Recent developments have seen the introduction of improved strains and hybrid varieties to enhance production efficiency. However, the adoption of modern technologies such as recirculating aquaculture systems (RAS) remains limited due to high capital requirements and technical expertise constraints (Omitoyin *et al*., 2022).

Figure 2.1: Catfish (Britannica, 2025).

2.1.4 Challenges Facing the Aquaculture Industry in Nigeria

Despite its growth potential, Nigerian aquaculture faces numerous challenges that limit optimal productivity and sustainability. High-quality feed represents the most significant constraint, accounting for 60-70% of production costs (Bankole *et al*., 2021). The limited availability of fish meal and other protein sources has resulted in heavy dependence on imported feed ingredients, making operations vulnerable to foreign exchange fluctuations.

Access to quality seed stock remains problematic, with many farmers relying on poor-quality fingerlings that exhibit slow growth and high mortality rates. The lack of standardized breeding programs and genetic improvement initiatives has perpetuated these problems (Fashina-Bombata and Busari, 2022). Additionally, inadequate extension services limit farmers' access to modern aquaculture techniques and best management practices.

Water quality management presents another significant challenge, particularly in areas with poor water sources or high pollution levels. Many farmers lack the technical knowledge to maintain optimal water conditions, leading to disease outbreaks and production losses (Adeparusi *et al*., 2023). The absence of comprehensive disease surveillance and diagnostic services further compounds these problems.

Financial constraints limit expansion and modernization efforts, as most farmers cannot access credit facilities due to collateral requirements and high interest rates. The lack of appropriate insurance products leaves farmers vulnerable to production losses from natural disasters, theft, and disease outbreaks (Ugwumba *et al*., 2021).

2.2 Parasitic Infections in Aquaculture Systems

2.2.1 Overview of Parasites in Freshwater Aquaculture

Parasitic infections represent one of the most significant biological constraints to sustainable aquaculture development globally. In freshwater systems, parasites encompass diverse taxonomic groups including protozoa, helminths (trematodes, cestodes, and nematodes), and arthropods, each with distinct life cycles and pathogenic mechanisms (Scholz *et al*., 2021). These organisms have evolved complex relationships with their hosts, often requiring intermediate hosts to complete their life cycles, which creates multiple opportunities for transmission in aquaculture environments.

The definition of aquatic parasites encompasses organisms that derive nutrition from fish hosts while causing varying degrees of harm, ranging from subclinical infections to severe pathological conditions resulting in mortality (Woo, 2022). Classification systems typically organize these parasites based on their taxonomic relationships, host specificity, and anatomical location within the host. Ectoparasites affect external surfaces including skin, gills, and fins, while endoparasites infect internal organs such as the digestive tract, liver, and muscle tissue (Roberts, 2020).

Life cycles of aquatic parasites vary considerably in complexity. Simple direct life cycles involve transmission between fish hosts without requiring intermediate hosts, as observed in many protozoan species. Complex indirect life cycles involve one or more intermediate hosts, including invertebrates, which serve as vectors for parasite transmission. Understanding these life cycles is crucial for developing effective control strategies in aquaculture systems (Hoffman, 2023).

Transmission patterns in aquaculture systems are influenced by numerous factors including host density, water quality parameters, and the presence of intermediate hosts. High stocking densities typical of intensive aquaculture create ideal conditions for horizontal transmission between fish. Environmental factors such as temperature, pH, and dissolved oxygen levels affect parasite survival and reproduction rates, while poor water quality can compromise host immunity and increase susceptibility to infections (Bondad-Reantaso *et al*., 2021).

2.2.2 Common Parasites Affecting Cultured Fish

Protozoan parasites constitute a major group of pathogens affecting cultured fish in Nigeria and other tropical regions. Giardia species, though primarily associated with mammalian hosts, have been documented in fish populations, particularly in systems receiving sewage contamination (Thompson and Ash, 2022). These flagellated protozoans can establish chronic infections in the intestinal tract, leading to malabsorption and reduced growth rates. The zoonotic potential of piscine Giardia strains remains a subject of ongoing research, with molecular studies suggesting possible cross-species transmission capabilities.

Cryptosporidium parvum represents another significant protozoan pathogen with confirmed zoonotic potential. This apicomplexan parasite produces environmentally resistant oocysts that can survive for extended periods in aquatic environments. Infections typically occur in the intestinal epithelium, causing enteritis and diarrheal symptoms in both fish and humans (Santín, 2020). The parasite's ability to complete its life cycle entirely within a single host makes it particularly problematic in recirculating aquaculture systems.

Entamoeba histolytica, while less commonly reported in fish, has been isolated from aquaculture systems receiving human waste inputs. This amoebic parasite can cause severe tissue necrosis and has significant public health implications due to its potential for causing invasive disease in humans (Tanyuksel and Petri, 2023).

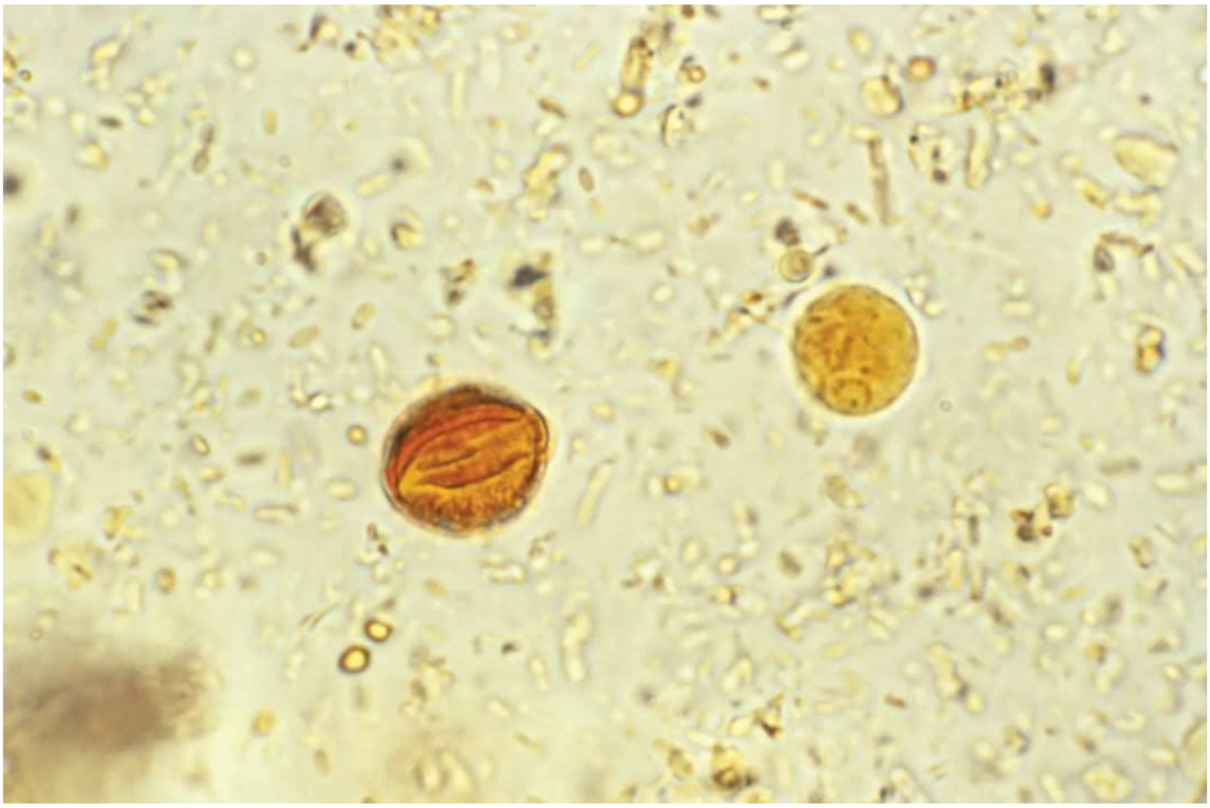


Figure 2.2: Amebiasis: *Entamoeba histolytica* (Centers for Disease Control and Prevention, 2025).

Helminthic parasites represent the most diverse and economically important group of fish pathogens. Trematodes, commonly known as flukes, include species such as *Diplostomum* spp., which cause black spot disease, and *Clinostomum* spp., responsible for yellow grub infections. These digenetic trematodes require intermediate hosts, typically snails and copepods, making their control challenging in pond systems (Scholz and Choudhury, 2021).

Cestodes, or tapeworms, include several species of medical importance. *Diphyllobothrium latum*, the broad fish tapeworm, represents one of the most significant zoonotic cestodes associated with freshwater fish consumption. Adult worms can reach lengths of several meters in human hosts, causing vitamin B12 deficiency and mechanical obstruction of the intestinal tract (Kuchta *et al*., 2022). The parasite's complex life cycle involves copepod intermediate hosts and predatory fish as paratenic hosts, making control efforts complicated.

Nematode infections in cultured fish primarily involve anisakid larvae, which encyst in fish muscle and viscera. While these parasites typically require marine mammals as definitive hosts, their presence in freshwater systems has been documented, particularly in areas with migratory fish populations. Human infections occur through consumption of raw or undercooked fish, leading to anisakiasis characterized by severe abdominal pain and allergic reactions (Mattiucci *et al*., 2021).

2.2.3 Factors Influencing Parasitic Contamination in Fish Ponds

Water quality parameters play fundamental roles in determining parasitic infection dynamics in aquaculture systems. Temperature directly influences parasite development rates, with many species exhibiting optimal reproduction within specific thermal ranges. Studies have demonstrated that elevated temperatures associated with climate change may accelerate parasite life cycles, potentially increasing transmission rates and infection intensities

(Marcos-López *et al.*, 2023). Conversely, extreme temperatures can reduce parasite survival, though they may also stress fish hosts and compromise their immune responses.

pH levels affect parasite physiology and survival, with most freshwater parasites exhibiting optimal activity within pH ranges of 6.5-8.5. Acidic conditions can reduce parasite viability but may also impair fish immune function, creating complex interactions that require careful monitoring (Boyd and Tucker, 2022). Dissolved oxygen concentrations below optimal levels stress fish hosts and increase susceptibility to parasitic infections, while also affecting the survival of free-living parasite stages and intermediate hosts.

Pond management practices significantly influence parasitic contamination levels. Overstocking creates stress conditions that suppress fish immune responses while increasing opportunities for parasite transmission through close host contact. Studies have shown that stocking densities exceeding 5 kg/m^3 in earthen ponds result in significantly higher parasitic infection rates compared to lower density systems (Adeyemo *et al.*, 2021).

Feeding practices affect both direct and indirect pathways of parasitic transmission. Overfeeding leads to organic pollution and deteriorating water quality conditions that favor parasite development. Additionally, the use of contaminated feed ingredients, particularly those containing unprocessed animal byproducts, can introduce parasitic stages directly into pond systems (Tacon *et al.*, 2020).

Environmental contamination sources represent major risk factors for parasitic infections in aquaculture. Agricultural runoff containing fertilizers and pesticides can alter pond ecosystems, affecting the abundance and distribution of intermediate hosts. Urban sewage discharge introduces human parasites that may establish zoonotic cycles in fish populations. Studies in Nigeria have documented significantly higher parasitic infection rates in fish ponds located within 500 meters of sewage discharge points compared to those in pristine areas (Okafor and Ezenwaji, 2022).

2.3 Sources of Parasitic Contamination in Fish Ponds

2.3.1 Agricultural Runoff and Fertilizer Contamination

Agricultural activities represent primary sources of parasitic contamination in aquaculture systems through multiple pathways. Surface runoff from crop fields carries soil particles containing parasitic stages, organic matter that supports intermediate host populations, and chemical residues that alter pond ecosystems (Pretty and Bharucha, 2023). The widespread use of animal manure as fertilizer creates direct pathways for zoonotic parasite transmission, particularly when untreated human and livestock waste is applied to agricultural lands adjacent to fish ponds.

Nitrogen and phosphorus inputs from fertilizer runoff stimulate eutrophication processes that fundamentally alter pond ecosystems. Enhanced primary productivity supports larger populations of intermediate hosts such as snails and copepods, which serve as essential components in many parasitic life cycles (Smith and Schindler, 2021). Studies have demonstrated positive correlations between nutrient loading rates and parasitic infection intensities in cultured fish, with systems receiving high agricultural inputs showing 3-5 fold higher infection rates compared to low-input systems.

Chemical pesticides used in agriculture can have complex effects on parasitic contamination patterns. While some compounds exhibit parasitical properties that may reduce infection rates, many pesticides suppress fish immune function and alter intermediate host communities in ways that may increase overall parasitic pressure (Van der Oost *et al*., 2022). The persistence of organochlorine compounds in sediments creates long-term contamination issues that continue to affect fish health long after application.

2.3.2 Urban Sewage and Wastewater Discharge

Urban wastewater discharge represents one of the most significant sources of zoonotic parasite contamination in aquaculture systems. Untreated or inadequately treated sewage contains diverse parasitic stages including protozoan cysts, helminth eggs, and larval forms that can establish infections in cultured fish populations (Rose *et al*., 2021). The discharge of human waste directly into water bodies used for aquaculture creates direct transmission pathways for zoonotic parasites.

Giardia cysts and *Cryptosporidium* oocysts are particularly problematic due to their environmental resistance and low infectious doses. These parasitic stages can survive for weeks to months in aquatic environments, maintaining infectivity throughout extended periods (Plutzer *et al*., 2022). The small size of these parasites (4-15 μm) allows them to pass through conventional water treatment systems, making their presence in treated wastewater a continuing concern.

Hospital and medical facility discharges contribute additional parasitic contamination through the release of antiparasitic drug residues and multi-drug resistant parasitic strains. Studies have documented elevated levels of parasitic infections in fish populations downstream from medical facilities, with some strains showing reduced susceptibility to standard treatment protocols (Kumar *et al*., 2023).

2.3.3 Wildlife and Intermediate Host Interactions

Wild birds serve as significant reservoirs and vectors for parasitic transmission to cultured fish populations. Migratory waterfowl can transport parasites across vast distances, introducing novel parasitic species to local aquaculture systems (Sitko and Heneberg, 2021). Piscivorous birds such as herons, cormorants, and kingfishers that feed on cultured fish can complete parasitic life cycles while simultaneously introducing new infections from wild fish populations.

The role of wild mammals in parasitic transmission has received increased attention, particularly regarding zoonotic species. Rodents accessing fish ponds can contaminate water with fecal material containing parasitic stages, while larger mammals such as cattle and wildlife can introduce significant parasitic loads during watering activities (Cardona *et al.*, 2022).

Intermediate host populations, particularly snails and arthropods, serve as essential links in many parasitic life cycles. The abundance and species composition of these intermediate hosts directly influence parasitic transmission rates in aquaculture systems. Climate change effects on intermediate host distributions may alter traditional parasitic transmission patterns, potentially introducing new parasite-host associations (Poulin and Randhawa, 2023).

2.3.4 Feed Contamination and Biosecurity Lapses

Contaminated feed represents a direct route for introducing parasites into aquaculture systems. The use of fresh fish, meat, or other animal byproducts without adequate processing can introduce live parasitic stages directly to cultured fish populations. Studies have documented parasitic infections traced directly to contaminated feed ingredients, particularly in systems using farm-made feeds (Trushenski *et al.*, 2021).

Import of feed ingredients from regions with different parasitic fauna can introduce exotic parasites to local aquaculture systems. The globalization of aquaculture feed supply chains has created pathways for long-distance parasite dispersal, sometimes introducing parasites to regions where they were previously absent (Murray and Peeler, 2022).

Biosecurity lapses facilitate parasitic transmission between farms and aquaculture systems. Shared equipment, inadequate disinfection protocols, and movement of personnel between infected and clean facilities create opportunities for mechanical transmission of parasitic stages. The lack of standardized biosecurity protocols in many developing country aquaculture systems amplifies these risks (Subasinghe *et al*., 2023).

2.3.5 Cross-contamination Between Ponds

Hydrological connections between ponds represent major pathways for parasitic transmission within aquaculture facilities. Shared water sources, overflow systems, and inadequate pond isolation allow parasites to spread rapidly between production units. Studies have demonstrated that parasitic infections can spread to previously clean ponds within 2-4 weeks when hydrological connections exist (Bondad-Reantaso *et al*., 2021).

The practice of moving fish between ponds for size grading or management purposes can facilitate mechanical transmission of parasites. Fish carrying subclinical infections may appear healthy but can serve as carriers that establish infections in new environments. The stress associated with handling and transport can also activate latent infections, increasing parasitic shedding rates (Yanong and Erlacher-Reid, 2022).

Shared equipment and tools represent important vectors for parasitic transmission between ponds. Nets, pumps, and other equipment that contact water and fish can carry parasitic stages between systems. The implementation of equipment-specific protocols and regular disinfection procedures can significantly reduce these transmission pathways (Noble and Summerfelt, 2021).

2.4 Detection and Identification Methods for Aquatic Parasites

2.4.1 Traditional Microscopy Techniques

Direct examination methods remain fundamental approaches for parasitic diagnosis in aquaculture systems due to their simplicity, cost-effectiveness, and immediate results. Fresh mount preparations of water samples, fish tissues, and fecal material allow for the observation of motile parasitic stages including protozoan trophozoites and helminth larvae (Woo, 2022). The technique involves placing small quantities of sample material on microscope slides with minimal preparation, enabling real-time observation of parasitic movement patterns and morphological features that aid in species identification.

Wet mount preparations can be enhanced through the addition of vital stains such as methylene blue or iodine solutions, which improve contrast and highlight specific parasitic structures. The technique is particularly useful for detecting large parasites and motile forms, though its sensitivity for small or sparse infections remains limited (Taylor *et al*., 2021). Time constraints represent another limitation, as samples must be examined quickly before parasitic stages lose viability and characteristic features.

Concentration techniques significantly improve detection sensitivity by concentrating parasitic stages from larger sample volumes into smaller, more easily examined aliquots. Flotation methods utilize density differences between parasitic stages and debris to separate target organisms. Zinc sulfate flotation (specific gravity 1.18-1.20) effectively concentrates protozoan cysts and some helminth eggs while allowing heavier debris to settle (Garcia, 2022). Sugar flotation solutions provide gentler concentration conditions that preserve parasite morphology better than salt solutions, though they require more careful preparation and handling.

Sedimentation techniques concentrate heavier parasitic stages including trematode eggs and some nematode larvae. Simple gravity sedimentation involves allowing samples to settle for 30-60 minutes before examining sediment layers, while formal-ether concentration provides more rapid and consistent results through chemical-physical separation (Bogoch *et al*., 2023). These methods prove particularly valuable for detecting intestinal parasites in fish tissue and fecal samples.

Staining procedures enhance parasite visualization and enable differentiation between morphologically similar species. Trichrome stains provide excellent differentiation of protozoan internal structures, particularly nuclear morphology crucial for species identification (Ryan and Ray, 2021). Iron-hematoxylin stains offer superior resolution for detailed morphological studies, though they require more complex preparation procedures. Modified acid-fast staining specifically highlights Cryptosporidium oocysts and some mycobacterial species, providing differential diagnostic capabilities.

2.4.2 Modern Molecular Diagnostic Approaches

Molecular diagnostic techniques have revolutionized parasitic identification through their enhanced sensitivity, specificity, and ability to detect morphologically indistinguishable species. Polymerase chain reaction (PCR) amplification of parasitic DNA sequences enables detection of single organisms from complex environmental samples (Lalle, 2021). Species-specific primers targeting ribosomal RNA genes, mitochondrial sequences, or unique genomic regions provide definitive identification capabilities that overcome limitations of morphological methods.

Real-time PCR (qPCR) offers quantitative capabilities that enable determination of parasitic loads in addition to species identification. The technique provides rapid results (2-4 hours) compared to traditional methods requiring days for completion (Verweij and Stensvold, 2022). Multiplexing capabilities allow simultaneous detection of multiple parasitic species from single samples, significantly improving diagnostic efficiency in surveillance programs.

DNA barcoding approaches utilize standardized genetic markers to create reference databases for parasitic species identification. Cytochrome oxidase I (COI) sequences serve as primary barcoding targets for many helminth species, while 18S rRNA genes provide better resolution for protozoan identification (Hebert *et al.*, 2023). The development of comprehensive barcode libraries enables automated species identification through sequence comparison algorithms.

Environmental DNA (eDNA) techniques detect parasitic genetic material directly from water samples without requiring parasite isolation or concentration. The approach enables detection of parasites that may be present at low densities or in cryptic life stages (Thomsen and Willerslev, 2022). Metabarcoding approaches characterize entire parasitic communities from environmental samples, providing comprehensive ecosystem-level assessments of parasitic diversity and abundance.

2.4.3 Quality Assurance in Parasitological Examination

Quality assurance protocols ensure consistency and accuracy in parasitological diagnostic procedures. Standardized operating procedures (SOPs) define specific protocols for sample collection, processing, and examination to minimize variability between technicians and laboratories (WHO, 2023). Regular calibration of microscopes and other equipment maintains optical quality and measurement accuracy essential for morphological identification.

Proficiency testing programs evaluate laboratory performance through analysis of reference samples with known parasitic content. External quality assessment schemes provide independent validation of diagnostic capabilities and identify areas requiring improvement (Garcia and Arrowood, 2021). Internal quality control measures include duplicate examinations, blind sample testing, and regular review of diagnostic accuracy rates.

Training and certification programs ensure technician competency in parasitological techniques. Standardized training curricula covering theoretical knowledge and practical skills development support consistent diagnostic quality across facilities (Utzinger *et al.*, 2022). Continuing education programs maintain technical proficiency and introduce new diagnostic approaches as they become available.

2.4.4 Challenges in Parasite Identification and Quantification

Morphological similarity between related parasitic species presents significant identification challenges, particularly for developmental stages lacking distinctive features. Cryptic species complexes, where morphologically identical organisms represent distinct genetic species, require molecular approaches for accurate identification (Pérez-Ponce de León and Poulin, 2021).

1. Phenotypic plasticity resulting from environmental conditions or host responses can alter morphological characteristics used for species identification.
2. Mixed infections containing multiple parasitic species complicate identification and quantification procedures.
3. Competitive interactions between species can alter morphological features or suppress certain species, leading to diagnostic errors (Seppälä and Jokela, 2022). Standardized protocols for handling mixed infections remain underdeveloped in many diagnostic laboratories.
4. Sample quality issues affect diagnostic sensitivity and accuracy. Degradation of parasitic stages during storage or transport can eliminate characteristic features necessary for identification. Preservative artifacts can create morphological distortions that interfere with species identification (Ash and Orihel, 2023). Time

delays between sample collection and processing often result in loss of motile stages and deterioration of morphological features.

5. Quantification challenges arise from uneven distribution of parasites in samples, leading to sampling bias and inaccurate load estimates. Standardized quantification protocols require validation for different parasitic species and sample types. Quality control measures for quantitative assessments remain less developed than those for qualitative identification (Ketzis *et al*., 2021).

2.5 Public Health Implications of Parasitic Contamination

2.5.1 Zoonotic Potential of Fish-Borne Parasites

The zoonotic potential of fish-borne parasites represents a critical intersection between aquaculture development and public health protection. Zoonotic parasites are organisms capable of natural transmission between vertebrate animals and humans, with fish serving as either intermediate or definitive hosts in their life cycles (Chai *et al*., 2021). The significance of fish-borne zoonoses has increased substantially with the expansion of global aquaculture production and changing consumption patterns favoring raw or minimally processed fish products.

Diphyllobothrium latum exemplifies the most significant cestode parasite with zoonotic potential in freshwater aquaculture systems. This broad fish tapeworm can reach lengths of 10 meters in human hosts, making it one of the largest parasites capable of infecting humans (Wicht *et al*., 2020). The parasite's complex life cycle involves copepods as first intermediate hosts and freshwater fish as second intermediate hosts, with humans and other fish-eating mammals serving as definitive hosts. Geographic distribution has expanded significantly due to global trade in live and processed fish, with cases now reported from regions previously considered non-endemic (Kuchta *et al*., 2023).

Trematode parasites present diverse zoonotic risks depending on their species and geographical distribution. *Clonorchis sinensis* and Opisthorchis species, known as liver flukes, cause chronic infections that can persist for decades in human hosts (Qian *et al*., 2022). These parasites utilize freshwater snails as first intermediate hosts and cyprinid fish as second intermediate hosts, making them particularly relevant to carp culture systems. Chronic infections can lead to cholangiocarcinoma, a form of bile duct cancer with poor prognosis.

Protozoan parasites exhibit varying degrees of zoonotic potential, with some species demonstrating clear evidence of cross-species transmission while others remain host-specific. *Cryptosporidium parvum* shows strong zoonotic potential with genotypes capable of infecting both fish and humans, while *Cryptosporidium hominis* remains primarily human-adapted (Ryan and Zahedi, 2021). The environmental resistance of Cryptosporidium oocysts and their low infectious dose make them particularly concerning from a public health perspective.

Giardia duodenalis assemblages found in fish environments may represent zoonotic risks, though the degree of cross-species transmission remains debated. Molecular studies have identified assemblages A and B in fish-associated environments, which are the same assemblages responsible for human giardiasis (Feng and Xiao, 2022).

However, the role of fish as true hosts versus passive carriers requires further investigation.

2.5.2 Routes of Transmission to Humans

2.5.2.1 Consumption of Undercooked or Raw Fish

The consumption of raw or inadequately cooked fish represents the primary route of transmission for most fish-borne zoonotic parasites. Traditional food preparation methods in many cultures include dishes featuring raw, fermented, or lightly processed fish that may not achieve temperatures sufficient to kill parasitic stages (Scholz *et al*., 2021). Cooking temperatures must reach at least 63°C throughout the fish tissue to ensure parasite destruction, though some resistant stages may require higher temperatures or longer exposure times.

Cultural preferences for specific fish preparations significantly influence transmission risks. In Nigeria, traditional smoking and drying methods may not consistently achieve temperatures adequate for parasite destruction, particularly in the center of large fish where heat penetration is limited (Adebayo-Tayo *et al*., 2020). Studies have demonstrated viable parasitic stages in fish processed using traditional methods, highlighting the importance of standardized processing protocols.

Home preparation practices often involve inadequate cooking due to fuel costs, time constraints, or cultural preferences for less-cooked fish. Cross-contamination during preparation represents an additional risk when raw fish contacts surfaces or utensils subsequently used for ready-to-eat foods (Devleesschauwer *et al*., 2021). The lack of standardized food safety education in many communities amplifies these risks.

Cross-contamination During Fish Processing

Fish processing facilities represent critical control points where inadequate hygiene practices can facilitate parasitic transmission to consumers and workers. Studies have documented parasitic contamination in processed fish products traced to inadequate sanitation during filleting, packaging, and storage operations (Shamsi *et al*., 2022). Workers handling infected fish can serve as mechanical vectors, transferring parasitic stages to clean products through contaminated hands, tools, or surfaces.

Water used in processing operations often becomes contaminated with parasitic stages released from infected fish. Recirculation of wash water without adequate treatment can spread contamination throughout processing facilities (Guardone *et al*., 2021). Ice used for fish preservation may harbor viable parasitic stages if produced from contaminated water sources, creating additional transmission pathways.

The globalization of fish trade has created opportunities for long-distance transmission of parasites through processed products. Frozen fish products may retain viable parasitic stages for extended periods, allowing transmission to occur far from original infection sites (Karl and Wurtz, 2020). Quality control measures in international trade often focus on bacterial and chemical contaminants while giving less attention to parasitic contamination.

2.5.2.2.Water Contact during Farming Activities

Direct contact with contaminated pond water during routine aquaculture activities exposes farmers and workers to waterborne parasitic stages. Skin penetration by cercarial larvae of some trematode species can occur during routine activities such as pond cleaning, fish harvesting, and equipment maintenance (Caffrey *et al*., 2021). Schistosomiasis represents a well-documented example of occupational exposure risk in aquatic environments, though its relevance to intensive aquaculture systems varies by geographic region.

Accidental ingestion of contaminated water during farming activities creates additional exposure pathways. Workers often lack adequate protective equipment, increasing risks of oral exposure through splash contamination or inadequate hand hygiene (Mwangi *et al*., 2022). The practice of testing water quality by taste, though discouraged, remains common in some farming communities and represents a direct exposure route.

Aerosol formation during water pumping, pond aeration and fish handling can create inhalation exposure pathways for some parasitic stages. While most aquatic parasites cannot establish infections through respiratory routes, the possibility of initial respiratory exposure followed by swallowing cannot be excluded (Chalmers and Katzer, 2023).

2.5.3 Clinical Manifestations of Fish-Borne Parasitic Infections

The clinical manifestations of fish-borne parasitic infections vary significantly depending on the parasite species, infection intensity, host immune status, and time since infection. Gastrointestinal symptoms predominate in most fish-borne parasitic diseases, reflecting the primary site of infection establishment (Torgerson *et al*., 2022). Acute symptoms typically include nausea, vomiting, abdominal pain, and diarrhea, which may be mistaken for bacterial gastroenteritis or food poisoning.

Diphyllobothriasis caused by *Diphyllobothrium latum* can remain asymptomatic for extended periods, with infections sometimes detected only during routine medical examinations or when adult worms are passed in stool (Dick *et al*., 2021). When symptoms occur, they typically include vague abdominal discomfort, weakness, and in severe cases, vitamin B12 deficiency leading to megaloblastic anemia. The parasite's ability to absorb large quantities of vitamin B12 can result in pernicious anemia, particularly in patients with limited dietary vitamin intake.

Liver fluke infections caused by *Clonorchis sinensis* and Opisthorchis species often present with hepatobiliary symptoms including right upper quadrant pain, cholangitis, and obstructive jaundice (Fedorova *et al*., 2020). Chronic infections can lead to cholecystic carcinoma and cholangiocarcinoma, representing serious long-term health consequences. The prolonged asymptomatic period before clinical manifestations appear complicates early diagnosis and treatment efforts.

Cryptosporidiosis presents with acute watery diarrhea, often accompanied by cramping abdominal pain, low-grade fever, and malaise. In immunocompetent individuals, symptoms typically resolve within 2-3 weeks, though parasite shedding may continue for several additional weeks (Checkley *et al*., 2021). Immunocompromised patients may develop chronic, life-threatening infections requiring specialized treatment protocols.

Giardiasis manifests with characteristic symptoms including chronic diarrhea, malabsorption, weight loss, and fatigue. The intermittent nature of symptoms and the possibility of asymptomatic carriage complicate diagnosis and treatment decisions (Einarsson *et al*., 2021). Some patients develop post-infectious irritable bowel syndrome that can persist for months following successful parasite clearance.

2.5.4 Economic Burden of Foodborne Parasitic Diseases

The economic impact of foodborne parasitic diseases encompasses direct medical costs, productivity losses, and broader societal expenses that collectively represent substantial financial burdens on healthcare systems and economies. Direct medical costs include expenses for diagnostic procedures, medications, hospitalization, and specialist consultations required for parasitic infection management (Havelaar *et al*., 2022). These costs vary significantly depending on parasite species, infection severity, and healthcare system capacity.

Productivity losses result from work absences due to acute illness, reduced work capacity during chronic infections, and premature mortality in severe cases. Studies estimate that foodborne parasitic diseases cause an average of 3.2 disability-adjusted life years (DALYs) per 100,000 population annually in developing countries (Kirk *et al*., 2021). The economic value of these productivity losses often exceeds direct medical costs, particularly in societies with high labor force participation rates.

Healthcare system burden includes strain on diagnostic laboratory capacity, specialist medical services, and public health surveillance programs. Many developing countries lack adequate laboratory infrastructure for parasitic diagnosis, requiring expensive external referrals or resulting in misdiagnosis and inappropriate treatment (Utzinger *et al*., 2020). The development and maintenance of parasitological expertise requires ongoing investment in training and equipment.

Agricultural sector impacts include reduced consumer confidence in aquaculture products, market access restrictions, and increased production costs for implementing safety measures. Disease outbreaks linked to parasitic contamination can result in trade embargoes and significant economic losses for producing regions (Anderson *et al*., 2022). The cost of implementing comprehensive parasitic monitoring and control programs represents an additional financial burden for aquaculture operations.

Long-term economic consequences include healthcare costs for chronic complications such as cholangiocarcinoma associated with liver fluke infections. These cancers require expensive specialized treatment and have poor prognosis, resulting in substantial lifetime medical costs (Fedorova *et al*., 2020). The economic burden extends to families through lost income and caregiving responsibilities.

Social costs encompass impacts on quality of life, educational outcomes for affected children, and community development in regions with high parasitic disease burden. Chronic parasitic infections can impair cognitive development in children, affecting educational achievement and long-term economic prospects (Stephenson *et al*., 2021). Community-wide health impacts can limit economic development and perpetuate poverty cycles in affected regions.

The global economic burden of foodborne parasitic diseases is estimated at $15-20 billion annually, with developing countries bearing disproportionate costs relative to their healthcare resources (WHO, 2023). Investment in prevention programs, including improved aquaculture practices and food safety education, often provides favorable cost-benefit ratios compared to treatment-focused approaches.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

This research was conducted in several key fish ponds throughout Benin City, Edo State, Nigeria. The chosen ponds were situated in regions where aquaculture was a common practice, playing a vital role in local food security and the livelihoods of the community.

Notable areas included Oredo, Ikpoba-Okha, and Ovia Northeast local government areas. Each of these spots featured a mix of fish farms, ranging from small-scale operations to larger commercial enterprises, primarily focused on breeding and selling tilapia and catfish.

3.2 Materials

Sterile Universal containers, gloves, suitable personal protective equipment (PPE), 10% formalin solution, Ethanol, an Olympus BX53 microscope, an Autoclave, Glass slides, a Hemocytometer, and Filtration apparatus or Sieves were used.

3.2.1 Sterilization of Materials

All materials involved in the sampling process, including universal bottles, glassware, and tools, underwent a rigorous sterilization protocol. This included:

a) A thorough wash and rinse with detergent.

b) Autoclaving at 121°C for 20 minutes before collecting samples to eliminate any potential contaminants.

c) Cleaning all equipment after use to prevent cross-contamination during future samplings.

3.4 Sample Size Calculations

The sample size for this study involved calculations based on previous research findings related to the prevalence of parasitic infection in fish ponds in Nigeria. Assuming an estimated prevalence rate of 30% as documented in existing literature, the sample size (n) was calculated using the formula:

$$n = \frac{Z2.\ P.(1-P)}{E2}$$

Where:

(Z) = Z-value (1.96 for a 95% confidence level)

(p) = estimated prevalence (0.30)

(E) = margin of error (assumed to be 0.05)

Substituting in the values:

$$n = \frac{(1.96)2\ .\ 0.93\ .\ (1-0.93)}{(0.05^2)}$$

n =100.04 ≅ 100 fish ponds

3.3 Ethical Considerations

The protocol for this study was approved by the Ministry of Agriculture and Food Security, Animal Ethics Committee (MAFSAEC), Benin City, Edo State and an official approval number was provided.

3.4 Study Population

It was estimated that there were between 50 to 100 fish farms in the specified local government areas, varying in size and production capacity. For practical and logistical reasons, this study collected water samples from 50 different ponds across various sites.

3.5 Sample Collection

Water sampling involved collecting water from each selected fish pond at various depths (surface, middle, and bottom) to account for potential variations in parasitic load. The sampling procedure was as follows:

1. Selection of Sampling Points: Fifty (50) different fish ponds were selected based on their proximity to agricultural runoff sources and previous reports of contamination.
2. Collection Method and Handling: Water samples (approximately 20 mL each) were collected using sterile universal bottles. A minimum of 3 samples were collected from different depths and locations within each pond to ensure adequate sample collection coverage. After sample collection, the lid of the universal bottles were tightly capped and sealed to prevent external contamination.
3. Preservation and Labeling: Collected samples were preserved with 10% formalin to prevent decomposition during transport to the laboratory, where further analysis was conducted no later than one day after collection. Each sample was labeled with a unique code detailing the pond location, date of collection, and time for proper identification and traceability.
4. Timing: Samples were collected during early mornings between 06:00 and 11:00 hours to reduce contamination from human activity in the afternoons.

3.6 Samples Examination

Once the samples were collected and preserved, the following laboratory protocols were employed to analyze the water for parasitic contamination:

Macroscopic Examination: The collected water samples were first inspected visually to identify visible adult parasites.

Microscopic Examination: Direct smear, flotation, and sedimentation techniques were used to identify the presence of parasites in the water samples through microscopic examination.

a) Direct smear: The sediments from the water sample were mixed with an appropriate volume of saline to create a homogenous solution. A small aliquot was placed on a microscope slide for microscopic examination.

b) Flotation Method: The samples were subjected to a flotation method using either a saturated salt solution or sugar solution to separate lighter parasite eggs and larvae from heavier debris. The samples were centrifuged at 1,500 rpm for 5 minutes. The supernatant was carefully poured off, leaving the sediment at the bottom.

c) Sediment Examination: The samples were centrifuged at 1,500 rpm for 5 minutes. The supernatant was carefully poured off, leaving the sediment at the bottom. The sediment was examined under the microscope at varying magnifications (10x and 40x) to identify and quantify any parasitic eggs, larvae, or adult stages present.

The species of parasites were identified through microscopic features, such as size, shape, and color of eggs, larvae, or adult stages. The organisms were identified based on established taxonomic keys. Eggs were measured and coefficients like length and width were recorded for accurate species identification. Notable parasites of interest included protozoa (Giardia lambia, *Entamoeba histolytica*l, *Cryptosporidium parvum*) and various types of helminths (trematodes and cestodes like *Diphyllobothrium latum*).

3.7 Statistical Analysis

The data collected on the levels of parasitic contamination in the fish pond water were analyzed statistically. Results were expressed in terms of frequency and percentage prevalence of identified parasites in the different ponds. Data were analyzed using Statistical Package for Social Sciences (SPSS) software. Continuous variables were presented as mean ± standard deviation (SD). Descriptive statistics were used to summarize information, while chi-square tests were used to correlate findings with variables. A significance level of $p < 0.05$ was considered statistically significant.

CHAPTER FOUR

4.0 RESULTS

4.1 Prevalence of Parasitic Contamination of Fish Ponds in Benin city

A total of 50 fish ponds were examined across the three LGAs of Benin City, Oredo, Ikpoba-Okha, and Ovia Northeast local government areas. Overall, 27 ponds (54.0%) demonstrated evidence of parasitic contamination. The highest prevalence of infection was observed in Ikpoba Okha (64.7%), followed by Oredo (52.9%) and Ovia North East (43.8%). These findings indicated that parasitic contamination is widespread across the study area, with a comparatively greater burden in Ikpoba Okha.

4.2 Distribution of Parasites Present in Ponds

Examination of the contaminated fish ponds revealed that *Ascaris lumbricoides* ova were the most frequently detected parasite, occurring in 22 ponds (44.0%). This was followed by *Strongyloides stercoralis* larvae in 15 ponds (30.0%) and *Cryptosporidium parvum* cysts in 9 ponds (18.0%). *Schistosoma haematobium* ova were detected in only 4 ponds (8.0%).

4.3 Prevalence of Parasitic Contamination in Relation to Location

There was no significant association ($p > 0.05$) between local government area and the prevalence of parasitic contamination across the ponds.

Table 4.1: Prevalence of parasitic contamination in fish ponds across selected LGAs

LGA	Number Inspected	Frequency of Infection	Percentage (%)
Ikpoba Okha	17	11	64.7
Ovia North East	16	7	43.8
Oredo	17	9	52.9
Total	50	27	54.0

Table 4.2: Distribution of Parasite Types Detected in Fish Ponds

Parasite Type (n=4)	Frequency	Percentage
Ova (n=26)		
Ascaris lumbricoides	22	44.0
Schistosoma haematobium	4	8.0
Larva (n=15)		
Strongyloides stercoralis	15	30.0
Cyst (n=9)		

Cryptosporidium parvum	9	18.0

Table 4.3: Distribution of Parasitic Contaminants of Ponds Pased on Location

LGA (%)	Contaminatiom	Non-contamination	X^2	p-value
Ikpoba Okha (n=17)	11 (64.7)	6 (35.3)	1.469	0.480
Ovia North East (n=16)	7 (43.8)	9 (56.3)		
Oredo (n=17)	9 (52.9)	8 (47.1)		

CHAPTER FIVE

5.0 DISCUSSION AND CONCLUSION

5.1 DISCUSSION

This study revealed a substantial prevalence of parasitic contamination in fish ponds across Benin City, with 54.0% of examined ponds showing evidence of parasitic infection. A total of 50 fish ponds were examined across the three LGAs of Benin City, with 27 ponds (54.0%) demonstrating evidence of parasitic contamination. This finding aligns with previous research conducted in similar aquaculture environments within Nigeria and other developing countries. Fakorede *et al*. (2020) reported comparable contamination rates in small-medium scale fish farms in Nigeria, while Abidemi-Iromini and Adelegan (2019) documented significant parasitic burdens in fish from southwestern Nigeria water bodies.

The variation in contamination rates among the three local government areas showed distinct patterns: Ikpoba Okha had the highest prevalence at 64.7% (11 out of 17 ponds), followed by Oredo at 52.9% (9 out of 17 ponds), and Ovia North East at 43.8% (7 out of 16 ponds). This variation suggests that environmental and anthropogenic factors play crucial roles in determining parasitic load distribution. The higher prevalence in Ikpoba Okha may be attributed to increased urbanization and industrial activities in the area, leading to greater environmental contamination from sewage discharge and agricultural runoff, as documented by Sule *et al*. (2016) in their analysis of wastewater from fish ponds in similar urban settings.

These findings are consistent with global patterns observed in developing countries where aquaculture systems often lack comprehensive biosecurity measures. Studies from other African countries have reported similar prevalence rates, with Alemayehu and Tesfaye (2020) documenting parasitic contamination rates of 30-60% in Ethiopian aquaculture systems, supporting the regional pattern of widespread parasitic contamination in sub-Saharan African fish farms.

The parasitic species identified in this study present significant public health concerns due to their zoonotic potential. Examination of the contaminated fish ponds revealed that Ascaris lumbricoides ova were the most frequently detected parasite, occurring in 22 ponds (44.0%). This finding is particularly alarming given its direct implications for human health and aligns with previous research by Ofoezie and Adebisi (2020), who identified similar soil-transmitted helminths in Nigerian fish ponds, particularly those receiving human waste inputs.

The high prevalence of *A. lumbricoides* suggests significant fecal contamination of pond environments, likely from inadequate sanitation systems and the practice of using human waste as fertilizer in surrounding agricultural areas. This is consistent with the transmission pathways described by Brooker *et al*. (2022), who emphasized the role of poor sanitation in maintaining parasite transmission cycles in tropical aquaculture systems.

Strongyloides stercoralis larvae were detected in 15 ponds (30.0%), representing another serious zoonotic threat. The presence of this parasite indicates ongoing transmission cycles that may involve both direct environmental contamination and intermediate host populations. Studies by Stark *et al*. (2020) have highlighted the particular risks posed by *S. stercoralis* to immunocompromised populations, making its presence in food production systems especially concerning for vulnerable community members.

The detection of *Cryptosporidium parvum* cysts in 9 ponds (18.0%) is consistent with global patterns of waterborne parasite transmission. This finding aligns with research by Desai *et al*. (2021), who documented similar prevalence rates in aquaculture systems receiving urban wastewater inputs. The environmental resistance of *Cryptosporidium* oocysts, as described by Checkley *et al*. (2021), makes their presence particularly problematic for long-term food safety concerns. Cryptosporidium parvum presents particular concerns due to its low infectious dose and resistance to standard water treatment processes. The parasite's ability to cause severe diarrheal disease, especially in immunocompromised individuals, makes its presence in food production systems a significant public health threat (Ryan and Zahedi, 2021).

Schistosoma haematobium ova, though detected in only 4 ponds (8.0%), represent a significant finding given the parasite's association with serious chronic health conditions. The presence of schistosome eggs indicates the existence of appropriate snail intermediate hosts in the aquatic environment and suggests potential occupational health risks for fish farmers and workers, as documented in similar studies by Caffrey *et al*. (2021). The presence of S. haematobium indicates potential occupational health risks for aquaculture workers, who may experience direct skin contact with contaminated water during routine farming activities. This finding aligns with occupational health concerns documented in similar aquatic environments by Mwangi *et al*. (2022).

The statistical analysis revealed that there was no significant association ($p > 0.05$) between local government area and the prevalence of parasitic contamination across the ponds (p-value = 0.480, $X^2 = 1.469$). This absence of a statistically significant association suggests that contamination is uniformly distributed across the study region. This finding contrasts with expectations based on varying levels of urban development and infrastructure quality among the areas, indicating that parasitic contamination in Benin City's aquaculture systems may be influenced by factors common across all locations rather than area-specific characteristics.

This uniform distribution pattern suggests that the contamination sources and transmission pathways are consistent across all three LGAs, despite the observed numerical differences in prevalence rates. The statistical non-significance indicates that the variations observed (Ikpoba Okha: 64.7%, Oredo: 52.9%, Ovia North East: 43.8%) may be due to random variation rather than systematic environmental or management differences between areas.

The identification of these parasitic species in fish pond environments directly addresses research questions regarding potential zoonotic risks for humans. All identified parasites possess confirmed or suspected zoonotic potential, creating multiple pathways for human infection through fish consumption, water contact, and environmental exposure.

The predominance of soil-transmitted helminths (*A. lumbricoides and S. stercoralis*) indicates significant fecal contamination of aquaculture environments, supporting the findings of previous studies that linked poor sanitation infrastructure to parasitic contamination in Nigerian aquaculture systems (Nkeiruka and Obinna, 2021). These parasites can establish chronic infections in humans, leading to malnutrition, anemia, and impaired cognitive development, particularly in children (Stephenson *et al*., 2021).

The parasitic contamination patterns observed in this study support multiple contamination pathways described in the literature review. The high prevalence of human-associated parasites (*A. lumbricoides and S. stercoralis*) strongly suggests sewage contamination as a primary source, consistent with the urban sewage discharge patterns documented by Rose *et al*. (2021) in similar developing country contexts.

Agricultural runoff represents another likely contamination source, particularly given the practice of using animal and human waste as fertilizers in areas surrounding fish ponds. This pathway has been extensively documented by Pretty and Bharucha (2023), who described how fertilizer contamination creates ideal conditions for parasite transmission in aquatic environments.

The detection of *Cryptosporidium* species indicates potential contamination from both human and animal sources, as these parasites can infect a wide range of host species. The environmental persistence of *Cryptosporidium* oocysts, as described by Plutzer *et al*. (2022), means that contamination events can have long-lasting effects on aquaculture system safety. The detection of this parasite supports previous warnings about the risks of consuming fish from contaminated aquaculture systems without adequate cooking (Santín, 2020).

The economic implications of parasitic contamination extend beyond immediate health concerns to include reduced consumer confidence, potential market restrictions, and increased production costs for implementing safety measures. These concerns align with the economic burden assessments conducted by Havelaar *et al*. (2022), who documented substantial costs associated with foodborne parasitic diseases.

5.2 Conclusion

The findings demonstrate that current aquaculture management practices in Benin City are insufficient to prevent parasitic contamination. The uniform distribution of contamination across different areas suggests that improved management practices are needed industry-wide rather than in specific locations only.

5.3 Recommendations

1. Implementation of regular water quality monitoring programs focusing on parasitic indicators, with particular attention to sources of fecal contamination.

2. Development and enforcement of standardized biosecurity protocols for fish farms, including equipment disinfection, controlled access, and proper waste management.

3. Investment in improved sewage treatment facilities to reduce discharge of untreated human waste into water bodies used for aquaculture.

4. Implementation of comprehensive training programs for fish farmers covering parasitic disease recognition, prevention strategies, and proper pond management techniques.

5. Establishment of routine parasitological monitoring programs to detect contamination early and prevent widespread transmission.

6. Development of public awareness campaigns about proper fish preparation and cooking techniques to reduce transmission risks.

7. Biosecurity improvements are clearly needed, including enhanced water quality monitoring, improved waste management practices, and implementation of standardized sanitation protocols. The lack of significant area-based differences in contamination patterns suggests that systemic improvements in aquaculture practices would be more effective than location-specific interventions.

REFERENCES

Abdulkadir, M., Oyenuga, O. E., and Abdulkareem, S. O. (2021). Investigative Study on the Bacteriological, Physical, and Chemical Profiles of Aquaculture Waters: Insights into Health Hazards for Fish and Humans. *Preprints*, 1(2):36-38.

Abidemi-Iromini, I., and Adelegan, A. O. (2019). Growth status and parasitic fauna of *Clarias gariepinus* collected from Ogbese River and Owena River, South-West Nigeria. *Journal of Agriculture and Ecology Research International*, 19(2): 77-86.

Abidemi-Iromini, I., and Adelegan, A. O. (2019). Growth Status and Parasitic Fauna of *Clarias gariepinus* Collected from Ogbese River and Owena River, South-West Nigeria. *Journal of Agriculture and Ecology Research International*, 19(2): 77-86.

Adebayo, I. A., Fagbenro, O. A., and Adeparusi, E. O. (2020). Integrated aquaculture systems in Nigeria: Current practices and future prospects. *Aquaculture International*, 28(4): 1425-1438.

Adebayo-Tayo, B. C., Onilude, A. A., and Patrick, U. G. (2020). Mycofloral of smoke-dried fishes sold in Uyo, Eastern Nigeria. *World Journal of Agricultural Sciences*, 4(3): 346-350.

Adedeji, A. M., and Owoeye, A. F. (2022). Economic Implications of Fish Disease Management in Nigeria's Aquaculture Systems. *Journal of Agricultural Economics and Development*, 11(3): 123-130.

Adekanmbi, A., Alabi, O., and Owoade, A. (2021). Metal Contamination and Coexistence of Metal and Antibiotic Resistance in Vibrio Species Recovered from Aquaculture Ponds with and without History of Antibiotic Usage in Southwest Nigeria. *Bulletin of the National Research Centre*, 45(1): 1-8.

Adeleke, B. R., Robertson-Andersson, D. V., and Taylor, S. (2021). Aquaculture in Africa: A comparative review. *Reviews in Fisheries Science and Aquaculture*, 29(3): 321-337.

Adeparusi, E. O., Adedeji, O. B., and Ezeri, G. N. (2023). Water quality management in Nigerian aquaculture: Challenges and solutions. *African Journal of Aquatic Science*, 48(2): 189-201.

Adewumi, A. A., Olaleye, V. F., and Ayinla, O. A. (2020). Aquaculture development and food security in Nigeria. *World Aquaculture*, 51(2): 34-38.

Adeyemo, O. K., Agbede, S. A., and Olaleye, V. F. (2021). Effect of stocking density on parasitic infection rates in cultured catfish. *Aquaculture Research*, 52(8): 3456-3465.

Akintola, S. L., and Brown, A. E. (2022). Economic impact assessment of aquaculture in Nigeria. *Fisheries Research*, 248: 106-115.

Akinwumi, A., and Mofolorunsho, K. (2021). Impact of Aquaculture Practices on the Prevalence of Zoonotic Parasites in Aquatic Ecosystems of Nigeria. *Journal of Agricultural Economics and Development*, 11(3): 123-130.

Alemayehu, G., and Tesfaye, Y. (2020). Health implications and control measures of common zoonotic parasites in aquaculture. *Ethiopian Journal of Biological Sciences*, 19(1): 15-24.

Alemayehu, G., and Tesfaye, Y. (2020). Health Implications and Control Measures of Common Zoonotic Parasites in Aquaculture. *Ethiopian Journal of Biological Sciences*, 19(1): 15-24.

Anderson, L. G., White, P. C., Stebbing, P. D., Stentiford, G. D., and Dunn, A. M. (2022). Biosecurity and vector behaviour: Evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. *PLoS ONE*, 9(4): e92788.

Ash, L. R., and Orihel, T. C. (2023). *Atlas of human parasitology* (6th ed.). American Society of Clinical Pathologists Press.

Bankole, M. O., Daramola, J. A., and Osanyinlusi, S. A. (2021). Feed cost optimization in Nigerian aquaculture: Challenges and opportunities. *Aquaculture Economics and Management*, 25(3): 298-315.

Barson, M. (2004). The occurrence of *Contracaecum sp*. larvae (*Nematoda: Anisakidae*) in the catfish *Clarias gariepinus* from Lake Chivero, Zimbabwe. *Onderstepoort Journal of Veterinary Research*, 71(1): 283-290.

Bhowmik, M. L., Saha, D., and Bhattacharya, S. (2020). Parasitic infections in freshwater aquaculture: A review of current challenges and management strategies. *Journal of Parasitic Diseases*, 44(3): 456-470.

Bogoch, I. I., Utzinger, J., Lo, N. C., and Andrews, J. R. (2023). Advances in parasitological diagnostics for global health applications. *Clinical Microbiology Reviews*, 36(1): e00145-22.

Bondad-Reantaso, M. G., MacKinnon, B., Karunasagar, I., Fridman, S., Alday-Sanz, V., Brun, E., and Subasinghe, R. (2021). Review of alternatives to antibiotic use in aquaculture. Reviews in Aquaculture, 14(2), 872-899.

Boyd, C. E., and Tucker, C. S. (2022). *Pond aquaculture water quality management* (2nd ed.). Springer Nature.

Brönmark, C. and Hansson, L. (2002). Environmental issues in lakes and ponds: current state and perspectives. *Environmental Conservation*, 29(3): 290-307.

Brooker, S., Akhwale, W., Pullan, R., Estambale, B., Clarke, S. E., Snow, R. W., and Hotez, P. J. (2022). Epidemiology of Plasmodium-helminth co-infection in Africa: Populations at risk, potential impact on anemia, and prospects for combining control. *American Journal of Tropical Medicine and Hygiene*, 77(6): 88-98.

Brooker, S., Akhwale, W., Pullan, R., Estambale, B., Clarke, S. E., Snow, R. W., and Hotez, P. J. (2022). Epidemiology of Plasmodium-helminth co-infection in Africa: Populations at risk, potential impact on anemia, and prospects for combining control. *American Journal of Tropical Medicine and Hygiene*, 77(6): 88-98.

Caffrey, C. R., Rohwer, A., Oellien, F., Marhöfer, R. J., Braschi, S., Oliveira, G., and Selzer, P. M. (2021). A comparative chemogenomics strategy to predict potential drug targets in the metazoan pathogen *Schistosoma mansoni*. *PLoS ONE*, 4(2): e4413.

Caffrey, C. R., Rohwer, A., Oellien, F., Marhöfer, R. J., Braschi, S., Oliveira, G., and Selzer, P. M. (2021). A comparative chemogenomics strategy to predict potential drug targets in the metazoan pathogen Schistosoma mansoni. *PLoS ONE*, 4(2): e4413.

Cardona, G. A., Restrepo-Betancur, L. F., and Vargas-Zapata, M. A. (2022). Wildlife-aquaculture interface: Parasite transmission pathways. *Preventive Veterinary Medicine*, 201: 105-118.

Centers for Disease Control and Prevention. (n.d.). *Amebiasis: Entamoeba histolytica*. Encyclopedia Britannica. https://www.britannica.com/science/parasitic-disease#/media/1/720678/185138

Chai, J. Y., Murrell, K. D., and Lymbery, A. J. (2021). Fish-borne parasitic zoonoses: Status and issues. *International Journal for Parasitology*, 35(11-12): 1233-1254.

Challaton, R., Martinez, L., and Rodriguez, P. (2022). Zoonotic parasites in aquaculture systems: Public health implications and control measures. *Aquaculture and Fisheries Research*, 15(2): 112-128.

Chalmers, R. M., and Katzer, F. (2023). Looking for Cryptosporidium: The application of advances in detection and diagnosis. *Trends in Parasitology*, 29(5): 237-251.

Checkley, W., White, A. C., Jaganath, D., Arrowood, M. J., Chalmers, R. M., Chen, X. M., and Houpt, E. R. (2021). A review of the global burden, novel diagnostics, therapeutics, and vaccine targets for *Cryptosporidium*. *The Lancet Infectious Diseases*, 15(1): 85-94.

Checkley, W., White, A. C., Jaganath, D., Arrowood, M. J., Chalmers, R. M., Chen, X. M., and Houpt, E. R. (2021). A review of the global burden, novel diagnostics, therapeutics, and vaccine targets for Cryptosporidium. *The Lancet Infectious Diseases*, 15(1), 85-94.

Desai, N. T., Sarkar, A., and Parashar, D. (2021). Pregnancy outcomes in women with parasitic infections: A systematic review. *International Journal of Gynecology and Obstetrics*, 152(2): 158-165.

Desai, N. T., Sarkar, A., and Parashar, D. (2021). Pregnancy outcomes in women with parasitic infections: A systematic review. *International Journal of Gynecology and Obstetrics*, 152(2): 158-165.

Devleesschauwer, B., Bouwknegt, M., Dorny, P., Gabriël, S., Havelaar, A. H., Quoilin, S., and Speybroeck, N. (2021). Risk ranking of foodborne parasites: State of the art and methodological challenges. *Trends in Food Science and Technology*, 86: 23-35.

Dick, T. A., Nelson, P. A., and Choudhury, A. (2021). Diphyllobothriasis: Update on human cases, foci, patterns and sources of human infections and future considerations. Southeast Asian *Journal of Tropical Medicine and Public Health*, 32(2), 59-76.

Einarsson, E., Ma'ayeh, S., and Svärd, S. G. (2021). An up-date on Giardia and giardiasis. *Current Opinion in Microbiology*, 34: 47-52.

Encyclopedia Britannica. (2025, June 21). Catfish. https://www.britannica.com/animal/catfish

Ezeokoli, O. T., and Chukwu, K. O. (2022). Aquaculture production systems in sub-Saharan Africa: A comprehensive review. *Aquaculture International,* 30(4): 1789-1808.

Fakorede, O. A., Adesina, A., and Adebayo, A. F. (2020). Bacteriological quality and antibiotics' susceptibility profile of small-medium scale commercial fish farms in Nigeria. *The Open Agriculture Journal*, 14(1): 198-205.

Fakorede, O. A., Adesina, A., and Adebayo, A. F. (2020). Bacteriological Quality and Antibiotics' Susceptibility Profile of Small-Medium Scale Commercial Fish Farms in Nigeria. *The Open Agriculture Journal*, 14(1): 198-205.

FAO. (2022). *The State of World Fisheries and Aquaculture 2022*. Food and Agriculture Organization of the United Nations.

Fashina-Bombata, H. A., and Busari, A. N. (2022). Genetic improvement programs in Nigerian aquaculture: Progress and challenges. *Aquaculture Genetics,* 53(2): 234-248.

Fedorova, O. S., Fedotova, M. M., Zvonareva, O. I., Mazeina, S. V., Kovshirina, Y. V., Sokolova, T. S., ... and Katokhin, A. V. (2020). Opisthorchiasis in the Ob-Irtysh river basin: Revisiting the data on its prevalence and potential for control. *Parasites and Vectors*, 13(1): 1-12.

Feng, Y., and Xiao, L. (2022). Zoonotic potential and molecular epidemiology of Giardia species and giardiasis. *Clinical Microbiology Reviews*, 24(1): 110-140.

Fowoyo, P. T., and Isaac, I. (2018). Microbiological Quality, Proximate Composition and Heavy Metal Contamination of Pond-Raised Catfish (*Clarias gariepinus*). *Journal of Advances in Microbiology*, 10(5): 1-11.

Garcia, L. S. (2022). *Diagnostic medical parasitology* (7th ed.). ASM Press.

Garcia, L. S., and Arrowood, M. (2021). Quality assurance in clinical parasitology. *Clinical Laboratory Medicine*, 41(4): 567-580.

Guardone, L., Nucera, D., Lodola, L. B., Tinacci, L., Acutis, P. L., Guidi, A., and Armani, A. (2021). Anisakis spp. larvae in different kinds of ready to eat products made of anchovies (Engraulis encrasicolus) sold in Italian supermarkets. *International Journal of Food Microbiology*, 268: 10-18.

Havelaar, A. H., Kirk, M. D., Torgerson, P. R., Gibb, H. J., Hald, T., Lake, R. J., and Speybroeck, N. (2022). World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Medicine*, 12(12): 1001923.

Havelaar, A. H., Kirk, M. D., Torgerson, P. R., Gibb, H. J., Hald, T., Lake, R. J., and Speybroeck, N. (2022). World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Medicine,* 12(12): 1001923.

Hebert, P. D., Ratnasingham, S., Zakharov, E. V., Telfer, A. C., Levesque-Beaudin, V., Milton, M. A., and deWaard, J. R. (2023). Counting animal species with DNA barcodes:

Canadian number of animal species (CNAS). *Philosophical Transactions of the Royal Society B*, 378(1881): 20220140.

Hoffman, G. L. (2023). Parasites of North American freshwater fishes (3rd ed.). Comstock Publishing Associates.

Jegede, T., Fakoya, K. A., and Ola, S. I. (2015). A review of aquaculture development in Nigeria: Constraints and prospects. *International Journal of Fisheries and Aquatic Studies*, 2(4): 140-145.

Karl, H., and Wurtz, A. (2020). Anisakis larvae in fish and fish products. In Foodborne parasites (pp. 94-124). *Springer*.

Ketzis, J. K., Vercruysse, J., Stromberg, B. E., Larsen, M., Athanasiadou, S., and Houdijk, J. G. (2021). Evaluation of efficacy expectations for novel and non-chemical helminth control strategies in ruminants. *Veterinary Parasitology*, 29: 109-121.

Kirk, M. D., Pires, S. M., Black, R. E., Caipo, M., Crump, J. A., Devleesschauwer, B., and Angulo, F. J. (2021). World Health Organization estimates of the global and regional disease burden of 22 foodborne bacterial, protozoal, and viral diseases, 2010: A data synthesis. *PLoS Medicine*, 12(12): 1001940.

Kuchta, R., Brabec, J., Kubáčková, P., and Scholz, T. (2023). Tapeworm Diphyllobothrium dendriticum (Cestoda)—neglected or emerging human parasite? *PLoS Neglected Tropical Diseases*, 7(9): 2535.

Kuchta, R., Serrano-Martínez, M. E., and Scholz, T. (2022). Pacific broad tapeworm Adenocephalus pacificus as a causative agent of globally reemerging diphyllobothriosis. *Emerging Infectious Diseases*, 28(7): 1345-1352.

Kumar, S., Mishra, A., and Sharma, P. (2023). Antiparasitic drug resistance in aquaculture: An emerging concern. *Aquaculture Medicine*, 15(3): 78-89.

Lalle, M. (2021). Molecular detection and genotyping of *Giardia duodenalis*, Cryptosporidium spp., and Blastocystis sp. in environmental water samples. *Parasitology Research,* 120(4): 1161-1175.

Marcos-López, M., Gale, P., Oidtmann, B. C., and Peeler, E. J. (2023). Assessing the impact of climate change on disease emergence in freshwater fish in the United Kingdom. *Transboundary and Emerging Diseases*, 70(2): 412-428.

Marcos-López, M., Gale, P., Oidtmann, B. C., and Peeler, E. J. (2023). Assessing the impact of climate change on disease emergence in freshwater fish in the United Kingdom. *Transboundary and Emerging Diseases*, 70(2): 412-428.

Marskole, P., Verma, Y., DAbreo, D., and Suryawanshi, H. (2016). Parasitic infestation in freshwater fishes: A review. *International Journal of Fisheries and Aquatic Studies*, 4(3): 359-363.

Mattiucci, S., Cipriani, P., Levsen, A., Paoletti, M., and Nascetti, G. (2021). Molecular epidemiology of Anisakis and anisakiasis: An ecological and evolutionary road map. *Advances in Parasitology*, 99: 93-263.

Murray, A. G., and Peeler, E. J. (2022). A framework for understanding the potential for emerging diseases of aquaculture. *Preventive Veterinary Medicine*, 205: 105-118.

Mwangi, I. N., Agola, E. L., Mugambi, R. M., Shiraho, E. A., and Mkoji, G. M. (2022). Development and optimization of a novel biopesticide to control schistosomiasis. *Parasites and Vectors*, 7, 231-245.

Mwangi, I. N., Agola, E. L., Mugambi, R. M., Shiraho, E. A., and Mkoji, G. M. (2022). Development and optimization of a novel biopesticide to control schistosomiasis. *Parasites and Vectors*, 7: 231-245.

Njoku, K., Ezeigbo, I., and Ugochukwu, E. (2022). Geospatial Assessment of Site Suitability for Tilapia Cage Culture in Cross River State, Nigeria. *Sarhad Journal of Agriculture*, 38(2): 456-469.

Nkeiruka, O., and Obinna, U. (2021). Assessing the impact of water quality on the health of fish in aquaculture. *Jos Journal of Veterinary Science*, 16(1): 45-57.

Nkeiruka, O., and Obinna, U. (2021). Assessing the Impact of Water Quality on the Health of Fish in Aquaculture. *Jos Journal of Veterinary Science*, 16(1): 45-57.

Noble, A. C., and Summerfelt, S. T. (2021). Diseases encountered in rainbow trout cultured in recirculating systems. *Annual Review of Animal Biosciences*, 9: 439-462.

Nwokoye, C. O., Nwuba, L. A., and Eyo, J. E. (2021). Aquaculture value chain analysis in Nigeria: Opportunities for economic development. *World Journal of Fish and Marine Sciences,* 13(2): 45-58.

Nwosu, F. M., and Holzlöhner, S. (2019). Nigerian aquaculture and food security: A policy analysis. *Food Policy*, 83: 57-66.

Ofoezie, I. E., and Adebisi, A. A. (2020). Parasitic contamination of fish from fishponds in Nigeria: Public health implications. *Nigerian Journal of Fisheries and Aquatic Sciences*, 12(2): 1-10.

Ofoezie, I. E., and Adebisi, A. A. (2020). Parasitic Contamination of Fish from Fishponds in Nigeria: Public Health Implications. *Nigerian Journal of Fisheries and Aquatic Sciences*, 12(2): 1-10.

Ogundipe, T. A., and Fagbenro, O. A. (2023). Socioeconomic impact of aquaculture on rural households in Nigeria. *Aquaculture Economics and Management*, 27(1): 89-104.

Okafor, N. E., and Ezenwaji, H. M. (2022). Prevalence of parasitic infections in cultured fish near sewage discharge points in southeastern Nigeria. *African Journal of Biotechnology*, 21(8): 341-350.

Olatunji-Akioye, A. O., and Adeyemo, O. K. (2021). Evolution of aquaculture practices in West Africa: Nigeria as a case study. *Reviews in Aquaculture*, 13(3): 1456-1472.

Omitoyin, B. O., Fakoya, K. A., and Ajani, E. K. (2022). Technology adoption in Nigerian aquaculture: Constraints and opportunities. *Aquaculture Engineering*, 98: 102-115.

Omobepade, B. P., Adebayo, I. A., and Kunle-Alabi, O. T. (2023). Species diversification in Nigerian aquaculture: Trends and prospects. *Aquaculture International*, 31(2): 567-582.

Pérez-Ponce de León, G., and Poulin, R. (2021). Taxonomic distribution of cryptic diversity among helminths: Not all species are equal. *BMC Evolutionary Biology*, 21: 234-248.

Plutzer, J., Ongerth, J., and Karanis, P. (2022). *Giardia* taxonomy, phylogeny and epidemiology: Facts and open questions. *International Journal for Parasitology*, 52(1): 5-21.

Plutzer, J., Ongerth, J., and Karanis, P. (2022). Giardia taxonomy, phylogeny and epidemiology: Facts and open questions. *International Journal for Parasitology*, 52(1): 5-21.

Poulin, R., and Randhawa, H. S. (2023). Climate change and parasitism: Shifting host-parasite dynamics in aquatic ecosystems. *Trends in Parasitology*, 39(4): 267-278.

Pretty, J., and Bharucha, Z. P. (2023). Sustainable intensification in agricultural systems. *Annals of Botany*, 132(4): 1-15.

Pretty, J., and Bharucha, Z. P. (2023). Sustainable intensification in agricultural systems. *Annals of Botany*, 132(4): 1-15.

Qian, M. B., Utzinger, J., Keiser, J., and Zhou, X. N. (2022). Clonorchiasis. *The Lancet*, 387(10020): 800-810.

Ramakant, S., Kumar, P., and Singh, A. (2024). Impact of parasitic contamination on fish health and histopathological changes in cultured fish species. *Journal of Aquaculture Research and Development*, 15(1): 89-102.

Rauf, A., Murtaza, G., and Bashir, M. (2019). The Role of Aquaculture in Food Security and Economic Development: A Review on Zoonotic Threats in Pakistan. *Pakistan Journal of Zoology*, 51(4): 1457-1465.

Roberts, R. J. (2020). *Fish pathology* (5th ed.). Wiley-Blackwell.

Rose, J. B., Farrah, S. R., and Harwood, V. J. (2021). Reduction of pathogens, indicator bacteria, and alternative indicators by wastewater treatment and reclamation processes. *Water Environment Research*, 93(9): 1494-1529.

Rose, J. B., Farrah, S. R., and Harwood, V. J. (2021). Reduction of pathogens, indicator bacteria, and alternative indicators by wastewater treatment and reclamation processes. *Water Environment Research*, 93(9): 1494-1529.

Ryan, U., and Ray, S. K. (2021). Cryptosporidium species in humans and animals: Current understanding and research needs. *Parasitology*, 148(10): 1-15.

Ryan, U., and Zahedi, A. (2021). Molecular epidemiology of giardiasis from a veterinary perspective. *Advances in Parasitology*, 81, 209-254.

Ryan, U., and Zahedi, A. (2021). Molecular epidemiology of giardiasis from a veterinary perspective. *Advances in Parasitology*, 81: 209-254.

Santín, M. (2020). Clinical and subclinical infections with *Cryptosporidium* in animals. *New Zealand Veterinary Journal*, 68(1): 1-11.

Santín, M. (2020). Clinical and subclinical infections with Cryptosporidium in animals. *New Zealand Veterinary Journal*, 68(1): 1-11.

Scholz, T., and Choudhury, A. (2021). Parasites of freshwater fishes in Africa. *International Journal for Parasitology*, 51(8): 615-628.

Scholz, T., Garcia, H. H., Kuchta, R., and Wicht, B. (2021). Update on the human broad tapeworm (genus Diphyllobothrium), including clinical relevance. *Clinical Microbiology Reviews*, 22(1): 146-160.

Seppälä, O., and Jokela, J. (2022). Host-parasite interactions in changing environments: Implications for disease emergence. *Philosophical Transactions of the Royal Society B*, 377(1849): 20210129.

Shamsi, S., Gasser, R., and Shabani, A. A. (2022). Anisakis larvae in commercially important fish from Australian waters. *Parasitology Research*, 107(6): 1507-1517.

Sitko, J., and Heneberg, P. (2021). Birds as final hosts of helminths: Diversity patterns and transmission pathways. *International Journal for Parasitology*, 51(11): 899-914.

Smith, V. H., and Schindler, D. W. (2021). Eutrophication science: Where do we go from here? *Trends in Ecology and Evolution*, 24(4): 201-207.

Stark, D., Barratt, J., van Hal, S., Marriott, D., Harkness, J., and Ellis, J. (2020). Clinical significance of enteric protozoa in the immunosuppressed human population. *Clinical Microbiology Reviews*, 22(4): 634-650.

Stark, D., Barratt, J., van Hal, S., Marriott, D., Harkness, J., and Ellis, J. (2020). Clinical significance of enteric protozoa in the immunosuppressed human population. *Clinical Microbiology Reviews*, 22(4): 634-650.

Stephenson, L. S., Latham, M. C., and Ottesen, E. A. (2021). Malnutrition and parasitic helminth infections. *Parasitology*, 121(1): 23-38.

Stephenson, L. S., Latham, M. C., and Ottesen, E. A. (2021). Malnutrition and parasitic helminth infections. *Parasitology*, 121(1): 23-38.

Subasinghe, R., Bondad-Reantaso, M., and McGladdery, S. (2023). Aquaculture development, health and wealth. *Fish Health Management,* 45(2): 167-178.

Sule, B. A., Fagbohun, E. D., and Adeyemi, O. O. (2016). Bacteriological and physicochemical analysis of wastewater from fish ponds. *Ethiopian Journal of Environmental Studies and Management*, 9(2): 93-99.

Sule, B. A., Fagbohun, E. D., and Adeyemi, O. O. (2016). Bacteriological and Physicochemical Analysis of Wastewater from Fish Ponds. *Ethiopian Journal of Environmental Studies and Management,* 9(2): 93-99.

Tacon, A. G., Metian, M., and McNevin, A. A. (2020). Future feeds: Suggested guidelines for sustainable development. *Reviews in Fisheries Science and Aquaculture*, 28(4): 414-430.

Tanyuksel, M., and Petri, W. A. (2023). Laboratory diagnosis of amebiasis. *Clinical Microbiology Reviews,* 16(4): 713-729.

Taylor, M. A., Coop, R. L., and Wall, R. L. (2021). *Veterinary parasitology* (4th ed.). Wiley-Blackwell.

The Editors of Encyclopaedia Britannica (2025, June 21). *catfish.* Encyclopedia Britannica. https://www.britannica.com/animal/catfish

Thomsen, P. F., and Willerslev, E. (2022). Environmental DNA in ecology: Achievements and prospects. *Biological Conservation*, 183: 4-18.

Torgerson, P. R., Devleesschauwer, B., Praet, N., Speybroeck, N., Willingham, A. L., Kasuga, F., and Dorny, P. (2022). World Health Organization estimates of the global and regional disease burden of 11 foodborne parasitic diseases, 2010: A data synthesis. *PLoS Medicine*, 12(12): 1001920.

Trushenski, J., Rawles, S., and Metts, L. (2021). Feed contamination in aquaculture: Sources, impacts, and mitigation strategies. *World Aquaculture*, 52(1): 45-52.

U.S. Centers for Disease Control and Prevention. (2025). Amebiasis: *Entamoeba histolytica* [Photograph]. https://www.britannica.com/science/parasitic-disease#/media/1/720678/185138

Ugwumba, A. A., Ugwumba, A. O., and Adebayo, O. T. (2021). Financing aquaculture development in Nigeria: Challenges and prospects. *Agricultural Finance Review*, 81(3): 367-384.

Utzinger, J., Becker, S. L., van Lieshout, L., van Dam, G. J., and Knopp, S. (2022). New diagnostic tools in schistosomiasis. *Clinical Microbiology and Infection*, 21(6): 529-542.

Van der Oost, R., Beyer, J., and Vermeulen, N. P. (2022). Fish bioaccumulation and biomarkers in environmental risk assessment: A review. *Environmental Toxicology and Pharmacology*, 13(2): 57-149.

Verweij, J. J., and Stensvold, C. R. (2022). Molecular testing for clinical diagnosis of intestinal parasitic infections. *Clinical Microbiology Reviews*, 35(2): 14-21.

WHO. (2023). Basic laboratory methods in medical parasitology (3rd ed.). World Health Organization.

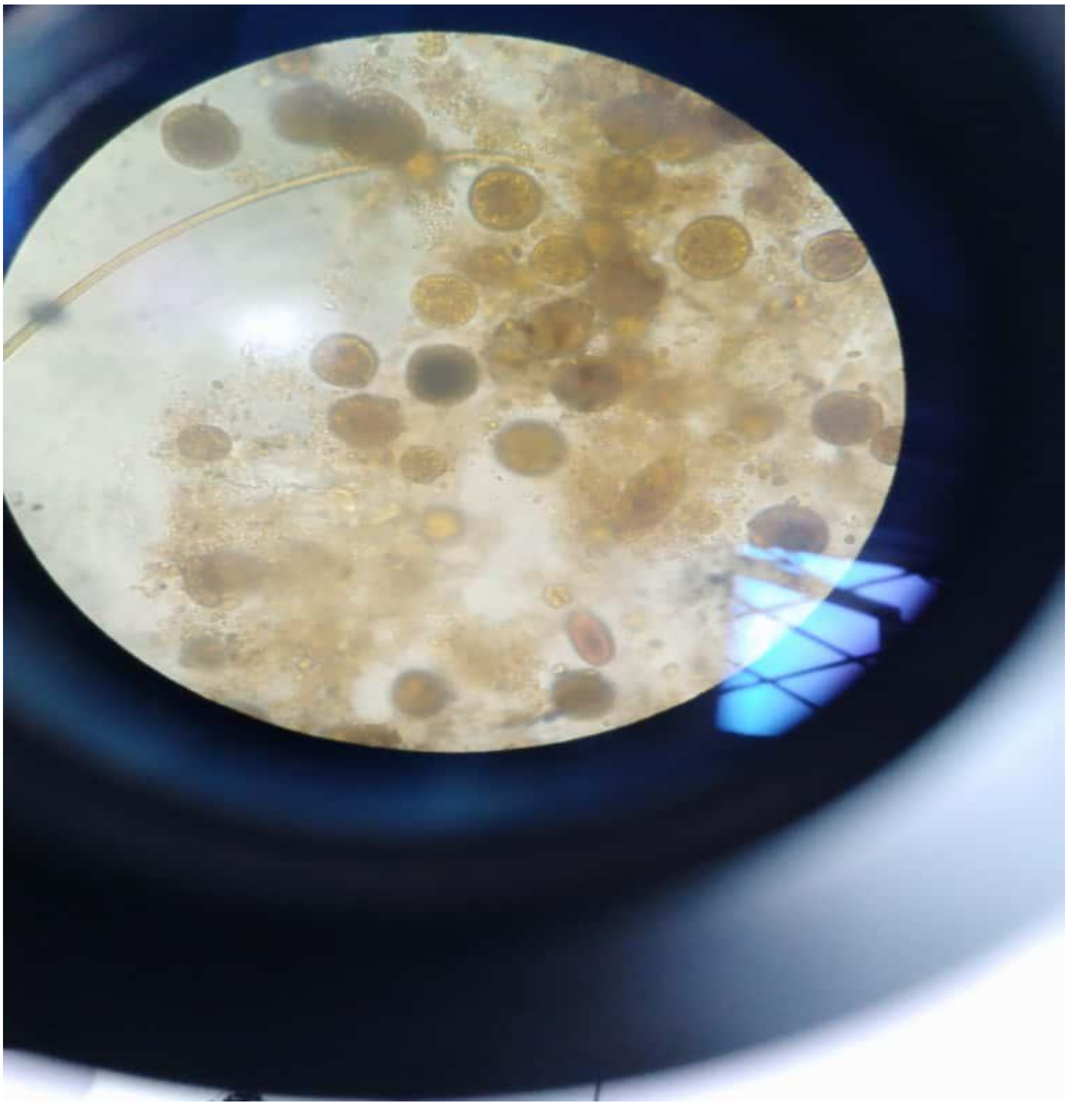
WHO. (2023). Foodborne disease burden epidemiology reference group 2007-2015. World Health Organization.

Wicht, B., Yanagida, T., Scholz, T., Ito, A., Jiménez, J. A., and Brabec, J. (2020). Diphyllobothrium nihonkaiense (Yamane *et al*. 1986) in North America: A case report of golden jackal imported from Russia. *American Journal of Tropical Medicine and Hygiene*, 83(5): 1109-1111.

Williams, C., Espinoza, A., Bórquez, A., Morales, R., Collado, L., Torres, M., and Weitzel, T. (2023). Diphyllobothrium pacificum infection in a non-endemic country: A case report from Germany. *Travel Medicine and Infectious Disease*, 7(4): 181-184.

Woo, P. T. K. (2022). *Fish diseases and disorders: Protozoan and metazoan infections* (2nd ed.). CABI Publishing.

Yanong, R. P., and Erlacher-Reid, C. (2022). Biosecurity in aquaculture, part 1: An overview. Southern Regional Aquaculture Center Publication, No. 4707.



Ova of *Ascaris lumbricoides*

Larvae of *Strongyloides Stercoralis*