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Improving aquaculture productivity in Uasin Gishu County, Kenya: Addressing pathogens, water quality, and management challenges

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Aquaculture in Uasin Gishu County, Kenya, has grown significantly due to government support, favorable climatic conditions, and an increasing demand for fish as a protein source. However, fish farming in the region faces severe challenges from pathogenic parasites and microbes, which significantly impact fish health and aquaculture productivity. Poor water quality, overcrowded ponds, and agricultural runoff exacerbate the proliferation of pathogens, including protozoan parasites (*Ichthyophthirius multifiliis*), monogeneans (*Gyrodactylus* species), bacterial pathogens (*Aeromonas hydrophila*, *Edwardsiella tarda*), and fungal infections (*Saprolegnia* species). These pathogens cause diseases that lead to high mortality rates, reduced productivity, and economic losses. This review synthesizes current research on fish pathogens in Uasin Gishu, contextualizing the findings within regional and global frameworks, and identifies critical gaps in disease management. It also proposes strategies to mitigate disease prevalence, improve water quality, and enhance aquaculture sustainability.

Key words: Food security, economic development, fish production, water quality, disease management.

INTRODUCTION

Aquaculture has emerged as one of the fastest-growing food production sectors worldwide, contributing to food security, livelihoods, and economic development. In Kenya, fish farming has transitioned from a subsistence activity to a significant economic driver, accounting for 24,000 metric tons of fish production in 2019 (FAO, 2020). Uasin Gishu County, located in Kenya's Rift Valley, has become a key aquaculture region due to its favorable climate and water resources. Tilapia

(*Oreochromis* species) and African catfish (*Clarias* species) are the most commonly farmed species, reflecting the national trend (KMFRI, 2019). Despite these advancements, aquaculture in Uasin Gishu faces substantial threats from fish diseases caused by pathogenic parasites and microbes, which significantly reduce fish productivity. Pathogenic parasites and microbes thrive under suboptimal water quality conditions, such as low dissolved oxygen levels, high

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ammonia concentrations, and contamination from agricultural runoff. These conditions are prevalent in Uasin Gishu, where many small-scale fish farmers struggle with inadequate infrastructure and limited technical knowledge. Diseases caused by these pathogens lead to high mortality rates, reduced growth, and economic losses, with some studies estimating that up to 30–50% of farmed fish mortality is attributable to disease outbreaks in the region (Muturi et al., 2018).

Globally, pathogenic parasites and microbes are recognized as significant constraints in aquaculture. In Southeast Asia and Latin America, disease outbreaks caused by similar pathogens have devastated fish farming industries, prompting extensive research into disease management and prevention strategies (Ribas and Pardo, 2014). In East Africa, including Kenya, Uganda, and Tanzania, research has identified poor water quality, overcrowding, and the lack of diagnostic facilities as key contributors to disease outbreaks (Mwanja et al., 2020). This review examines the diversity, prevalence, and impact of pathogenic parasites and microbes in Uasin Gishu County. It synthesizes findings from regional and global studies to propose actionable strategies for mitigating disease risks in aquaculture.

MATERIALS AND METHODS

Research design

This study employs a systematic literature review approach to synthesize research on aquaculture in Uasin Gishu County, Kenya. Key areas of focus include development trends, challenges, and sustainability practices.

Data sources and search strategy

Literature was sourced from databases such as Google Scholar, PubMed, and government reports. Keywords used included “Aquaculture in Uasin Gishu County,” “Fish farming challenges Kenya,” and “Sustainability in Kenyan aquaculture.” Articles were selected based on relevance to Uasin Gishu County and their focus on current aquaculture challenges.

Data extraction and synthesis

Data extracted from each study included study objectives, findings on water quality, species farmed, disease prevalence, and government initiatives. Thematic analysis was applied to group findings into categories like sustainability challenges and production systems.

RESULTS AND DISCUSSION

Aquaculture production systems

Like the broader Kenyan aquaculture sector, fish farming

in Uasin Gishu predominantly relies on extensive and semi-intensive production systems, with limited adoption of intensive systems due to high costs and technical barriers (FAO, 2016). These systems are primarily geared towards farming tilapia (*Oreochromis* spp.) and African catfish (*Clarias* spp.), the most popular species among local farmers due to their adaptability and market demand.

Semi-intensive aquaculture is the dominant practice, as it strikes a balance between affordability and productivity. Farmers use organic fertilizers, such as poultry and cattle manure, to enhance pond productivity by promoting the growth of natural food sources like phytoplankton and zooplankton. Supplementary feeding with cereal bran from maize, wheat, and rice is also common, reducing reliance on costly commercial feeds (Munguti et al., 2012). Moreover, semi-intensive systems are often integrated with crop and livestock farming, a practice widespread in Uasin Gishu.

This integration promotes resource efficiency and provides multiple income streams for smallholder farmers, underscoring the economic and environmental benefits of polyculture systems (Ogello et al., 2013). However, nutrient overloading in ponds due to excessive manure application can lead to eutrophication, which promotes the growth of pathogenic microbes and parasites, posing risks to both fish health and water quality (Nyandat and Owiti, 2013). Proper water quality management practices and sustainable fertilization strategies are necessary to mitigate these risks while maintaining productivity. While intensive aquaculture systems offer higher yields, they remain relatively rare in Uasin Gishu due to high operational costs. These include expenses associated with electricity for aeration systems and high-quality formulated feeds. Despite these constraints, farmers who adopt intensive practices have demonstrated their economic potential, with reports of annual profits reaching up to US\$11,000/ha (Mbugua, 2008). However, compared to aquaculture systems in Southeast Asia, which have successfully scaled up intensive practices through investments in technology and feed innovation, Uasin Gishu’s aquaculture sector remains at an early stage of development (Ribas and Pardo, 2014).

The adoption of intensive systems requires significant investment in infrastructure, biosecurity, and feed innovation—areas where Uasin Gishu currently lags. Improved access to affordable aeration technology and high-quality feeds, along with farmer training programs focused on disease prevention and water quality management, could facilitate the transition to more productive systems.

Integration of aquaculture with agriculture

Agriculture is the backbone of Uasin Gishu’s economy,

with widespread cultivation of maize, wheat, and horticultural crops alongside commercial livestock production. Integrated aquaculture-agriculture systems are particularly prominent in the county, reflecting a broader national trend (Ogello and Munguti, 2016). Farmers integrate fish farming with cattle, poultry, and crop production to optimize resource use and increase farm resilience. For example, manure from cattle and poultry is used to fertilize fish ponds, while pond water, enriched with nutrients from fish waste, is applied to crops, improving soil fertility and crop yields.

However, these practices present challenges. Nutrient overloading in ponds increases the risk of eutrophication, promoting the growth of pathogenic microbes and parasites (Nyandat and Owiti, 2013). Addressing these concerns requires proper water quality management and disease prevention strategies, which are essential for sustaining integrated systems in the long term. By promoting balanced nutrient application and better management practices, the benefits of integration can be maximized without compromising fish health and productivity.

Water quality and its challenges in aquaculture

Water quality is a critical factor influencing the sustainability of aquaculture in Uasin Gishu County and Kenya at large. Poor management practices, including the overuse of organic fertilizers like livestock manure, often lead to oxygen depletion and high ammonia levels in ponds, creating stressful environments for fish and promoting disease outbreaks (Boyd, 1998; Ngugi and Manyala, 2007). Such issues are further compounded by inadequate waste removal and agricultural runoff, which degrade water quality and exacerbate the proliferation of pathogenic microbes and parasites (Liti et al., 2005; Huicab-Pech et al., 2024).

Globally, research highlights the importance of maintaining optimal water quality parameters such as dissolved oxygen, temperature, pH, and ammonia levels for aquaculture productivity. For instance, Nile tilapia, the most commonly farmed species in Uasin Gishu, requires DO levels above 3 mg/L, a temperature range of 20–35°C, and a pH of 6.5–9.0 for optimal growth and survival (Popma and Masser, 1999; Boyd and McNevin, 2015). Deviations from these conditions can induce stress, weaken immunity, and increase susceptibility to diseases such as *Aeromonas hydrophila* infections and parasitic infestations by *Gyrodactylus* spp. (Zorriehzahra et al., 2023; Muturi et al., 2018).

In Kenya, the integration of fish farming with agriculture—such as using livestock manure to fertilize ponds and nutrient-rich pond water for crop irrigation—is a common practice, especially in Uasin Gishu. While this approach maximizes resource efficiency, it also elevates

nutrient loads in ponds, leading to eutrophication and the buildup of harmful compounds like ammonia and nitrites (Ogello et al., 2013; Ogello and Munguti, 2016). These conditions mirror challenges observed globally, particularly in regions with semi-intensive systems like Southeast Asia and Latin America, where high nutrient loads and poor water management increase the risk of disease outbreaks (Ribas and Pardo, 2014).

Efforts to mitigate water quality challenges in Uasin Gishu include introducing aeration systems, regular pond cleaning, and biosecurity measures, but their adoption is limited due to high costs and technical expertise requirements (FAO, 2020; Rahman et al., 2019). Research from Kenya and beyond emphasizes that consistent monitoring of key water parameters, maintaining appropriate stocking densities, and reducing nutrient overloading are critical for enhancing water quality and reducing fish stress (Ngugi et al., 2007; Boyd and Tucker, 2014). By addressing these challenges, Uasin Gishu can improve aquaculture productivity and align with global best practices for sustainable fish farming.

Pathogenic diseases in aquaculture

Bacterial diseases

Bacterial infections pose significant threats to aquaculture, particularly in Uasin Gishu County and Kenya at large, due to suboptimal water quality and poor management practices. Opportunistic bacteria such as *Aeromonas hydrophila*, *Flavobacterium columnare*, and *Edwardsiella tarda* are prevalent, often becoming pathogenic under conditions of stress, overcrowding, and nutritional imbalances (Sandeep et al., 2016; Lee et al., 2023). Diseases like columnaris, caused by *Flavobacterium columnare*, and hemorrhagic septicemia, caused by *Aeromonas hydrophila*, result in high fish mortality rates, particularly during early life stages such as fry and fingerlings (Ahmed and Kumar, 2005; Wang et al., 2024).

Comparative studies highlight similar patterns in global aquaculture. In Southeast Asia, ulcerative disease syndrome (EUS), caused by *Aphanomyces invadans* in synergy with bacterial infections has caused millions of dollars in losses (Mukherjee, 2002; Singh et al., 2024). In Uasin Gishu, bacterial diseases are exacerbated by high stocking densities, low dissolved oxygen levels, and poor pond management. Effective disease control involves improving water quality, maintaining biosecurity measures, and implementing health monitoring practices (Table 1).

Parasitic diseases

Parasitic infestations, such as ichthyophthiriasis ("white spot disease") caused by *Ichthyophthirius multifiliis* and

Table 1. Common bacterial diseases in aquaculture in Uasin Gishu County.

Disease condition	Symptoms	Pathogens Involved
Columnaris disease	Hemorrhagic and ulcerative lesions on fins, head, back.	<i>Flavobacterium columnare</i>
Tail and Fin Rot	Erosions, discoloration, and disintegration of fins and tails.	<i>Aeromonas hydrophila</i> , <i>Pseudomonas</i> spp.
Bacterial gill disease	Gasping, lethargy, discolored gills, secondary fungal infection.	<i>Flavobacterium branchiophilum</i> , <i>Cytophaga</i> spp.
Aeromoniasis	Hemorrhagic and ulcerative lesions on skin, fins, head.	<i>Aeromonas hydrophila</i> , <i>A. veronii</i> bv. <i>sobria</i>
Edwardsiellosis	Ulcerative abscesses in internal organs, hemorrhagic ulcers on skin.	<i>Edwardsiella tarda</i>
Vibriosis	Ulcerative abscesses, hemorrhagic ulcers on skin and internal organs.	<i>Vibrio anguillarum</i> , <i>V. parahaemolyticus</i>
Eye disease	Cataracts, corneal damage, eyeball putrefaction.	<i>Aeromonas liquefaciens</i> , <i>Staphylococcus aureus</i>
Pseudomoniasis	Hemorrhagic lesions on skin, fins, tail.	<i>Pseudomonas</i> spp.
Enteric red mouth disease	Hemorrhagic lesions around mouth, fins, tail, and internal hemorrhages.	<i>Yersinia ruckeri</i>

argulosis caused by *Argulus* spp., are among the most significant challenges in freshwater aquaculture in Uasin Gishu. These parasites cause damage to fish skin and gills, leading to respiratory distress, secondary bacterial infections, and significant economic losses (Walker et al., 2004; Mukherjee, 2002). Monogenean parasites like *Gyrodactylus* spp. and *Dactylogyru*s spp. are also prevalent, causing tissue destruction and impairing respiration (Sahoo et al., 2013; Zhu et al., 2024).

Crustacean ectoparasites like *Lernaea* spp. (anchor worms) and *Argulus* spp. (fish lice) affect dermal tissues, reducing growth and increasing susceptibility to disease. Seasonal variations and poor pond management intensify these issues. Farmers frequently rely on chemical treatments for control, although such practices have ecological and financial implications (Farhaduzzaman et al., 2010; Das and Mishra, 2014) (Table 2).

Viral diseases

Viral pathogens are less common in Kenya but

have the potential to cause devastating outbreaks. Infections such as koi herpesvirus (KHV) and viral hemorrhagic septicemia virus (VHSV) are documented globally and present risks to Kenya's expanding aquaculture. KHV, affecting koi and common carp, is characterized by gill necrosis and erratic swimming behavior, while VHSV impacts various species with hemorrhages and high mortality (Haenen et al., 2004; Levin et al., 2024).

In neighboring countries such as Uganda, viruses like tilapia lake virus (TiLV) have begun to affect farmed Nile tilapia populations in Lake Victoria, raising concerns about its potential spread to Kenya (Bacharach et al., 2016; Njiru et al., 2023). Effective management of viral diseases requires enhanced biosecurity, improved diagnostics, and investment in vaccines.

Fish disease management in Kenya

Fish disease management has become increasingly important in Kenya, especially in

Uasin Gishu County and the North Rift region, due to the rapid growth of aquaculture as a key economic activity. The intensification of aquaculture, characterized by the increased stocking density of fish, has led to higher risks of disease outbreaks, which can have devastating effects on fish populations, fish farmers' livelihoods, and regional economies. Factors such as environmental stress, poor water quality, and the introduction of fish from different regions without proper health screening have been identified as primary contributors to the spread of fish diseases (Mohapatra et al., 2012; Opiyo et al., 2018). This situation is compounded by global concerns, including climate change, which exacerbates environmental stressors affecting fish health (DeBrosse et al., 2022; FAO, 2023).

Factors influencing disease outbreaks in aquaculture

Fish diseases arise due to the interaction between the host (fish), pathogen (disease-causing agents), and the environment (such as water

quality, temperature, and stress). These factors are

Table 2. Common parasitic diseases in aquaculture.

Disease Condition	Symptoms	Pathogens Involved
Ichthyophthiriasis (Ich)	Whitish cysts on skin, fins, and gills.	<i>Ichthyophthirius multifiliis</i>
Trichodiniasis	Whitish cysts on skin, fins, and gills.	<i>Trichodina</i> spp.
Dactylogyrosis (Gill Fluke)	Destruction of gill filaments, white masses on gills.	<i>Dactylogyrus</i> spp.
Gyrodactylosis (Skin Fluke)	Destruction of skin and gills with white masses.	<i>Gyrodactylus</i> spp.
Argulosis (Carp Lice)	Skin lesions, secondary bacterial infections, hemorrhagic spots.	<i>Argulus</i> spp.
Myxosporidiasis	Cysts on body, internal organs, and gill filaments.	<i>Myxosporidium</i> spp.

Source: Austin and Austin (2012).



Figure 1. The interaction between host, pathogen, and environment in the development of fish diseases.

Source: Adapted from Bondad-Reantaso et al. (2005).

illustrated in the host-pathogen-environment model (Bondad-Reantaso et al., 2005) (Figure 1).

In the North Rift region, environmental factors such as poor water quality and temperature fluctuations are significant contributors to stress in fish, making them more susceptible to infections (Assefa and Abunna, 2018). Key pathogens identified in this region include *Aeromonas hydrophila* and *Streptococcus iniae*, which are responsible for bacterial infections in Nile tilapia and African catfish (Magundu et al., 2011; Rosowo et al., 2021).

The movement of live fish for aquaculture purposes, particularly the transportation of broodstock and fingerlings, further amplifies the risk of spreading diseases across regions and borders. This practice, while essential for the aquaculture industry, can inadvertently introduce new pathogens into local fish populations (Bondad-Reantaso et al., 2005). This translocation of fish without adequate quarantine measures has been recognized as a significant pathway for the introduction of both endemic and exotic diseases in Kenya (Opiyo et al., 2018).

Despite some advancement in aquaculture, fish

disease management in Kenya still faces significant challenges, particularly in the North Rift region. One of the major issues is the limited capacity for disease diagnostics. Although policies exist that promote fish health management, the lack of diagnostic laboratories, quarantine facilities, and specialized expertise in fish diseases remain significant bottlenecks to effective disease management (Akoll and Mwanja 2012). In Uasin Gishu County, for example, the absence of adequate disease surveillance infrastructure limits the timely detection of disease outbreaks, making it harder to manage and control infections effectively (Rosowo et al., 2021).

Farmers in this region largely depend on traditional knowledge and experience to manage diseases, often resorting to chemical treatments without accurate diagnoses of the underlying pathogens (Lewo and Obwaga, 2007). This approach is unsustainable, as it may lead to the misuse of antibiotics and other chemicals, increasing the risk of antibiotic resistance in aquaculture systems (Nyonje et al., 2018; Subasinghe, 1996). As pointed out by Cabello et al. (2016), the overuse of antibiotics like oxytetracycline, which is still

common in some private hatcheries, poses serious risks, not only to fish populations but also to human health, as resistant bacteria can potentially be transmitted to humans through the consumption of contaminated fish.

Commonly used treatments and concerns

In Uasin Gishu County, fish farmers rely on several prophylactic measures to reduce the likelihood of disease outbreaks. Common chemicals used include potassium permanganate and sodium chloride to eliminate bacterial and fungal infections (Rosowo et al., 2021). However, the over-reliance on chemical treatments is concerning, as it not only increases the risk of developing resistant pathogens but also has detrimental effects on the aquatic environment (Henriksson et al., 2018). To address this, there is a growing emphasis on alternative, non-antibiotic-based disease include the use of indigenous plant extracts, provide a more sustainable solution for managing fish diseases in the region (Boussini et al., 2021).

The future of fish disease management in Uasin Gishu County and the North Rift region lies in a multi-pronged approach that emphasizes preventive measures, improved surveillance, and sustainable treatments. Enhanced disease surveillance is essential to monitor fish health and detect emerging pathogens in real time. Government agencies, such as the Kenya Marine and Fisheries Research Institute (KMFRI), are currently working on programs to improve disease surveillance in aquaculture systems across the country, with a focus on regions like Uasin Gishu (KMFRI, 2024). Farmers and extension officers need training on best practices for disease management, including the proper use of chemicals and non-antibiotic treatments. Strict biosecurity protocols should be enforced to minimize the spread of diseases, especially during the transportation of live fish between regions. Quarantine facilities must be established to monitor and screen fish before they are introduced to new environments.

There is also a growing need to invest in the development of vaccines against key fish pathogens, which could drastically reduce the reliance on chemical treatments and antibiotics in aquaculture (Henriksson et al., 2018; Opiyo et al., 2018). As of 2023, workshops and educational initiatives led by the Food and Agriculture Organization (FAO) and local research institutes have been rolled out to raise awareness on biosecurity measures and best practices for disease prevention in aquaculture. In 2024, KMFRI is expected to launch a comprehensive fish disease surveillance program that will involve real-time monitoring of disease outbreaks in key aquaculture regions, including Uasin Gishu County (FAO, 2023; KMFRI, 2024).

Furthermore, research on the use of plant-based

alternatives for fish disease management continues to gain traction, with local universities and research centers exploring various indigenous plants that exhibit antimicrobial properties (Ndegwa et al., 2024). These developments provide hope for a more sustainable future in aquaculture disease management.

Challenges in fish health management

Fish health management in Kenya is hindered by significant challenges, particularly due to the absence of quarantine facilities and insufficient biosecurity measures to monitor the introduction and spread of diseases. Lewo and Obwaga (2007) emphasized that the lack of reported fish diseases, coupled with a shortage of specialized human resources in aquaculture health, discourages the establishment of necessary quarantine measures. This issue is exacerbated by the increasing importation of non-indigenous species, notably Nile tilapia broodstock, which elevates the risk of introducing diseases and parasites (Njagi, 2016).

The inadequacy of biosecurity protocols to prevent the escape of cultured fish into wild habitats further jeopardizes local fish populations (Hickley et al., 2008). Such escapes can lead to genetic dilution of native stocks and increased competition for resources (Ogutu-Ohwayo et al., 2020). The absence of robust biosecurity measures can facilitate the rapid spread of pathogens throughout the region, compromising both wild and cultured fish populations (Hickley et al., 2008).

The detection of TiLV in the Tanzanian and Ugandan parts of Lake Victoria highlights the vulnerability of farmed fish in cages to infectious diseases. While there have been no clinical signs or mortality linked to TiLV in these regions, the virus has resulted in substantial losses in Nile tilapia stocks in countries such as Israel, Ecuador, and Egypt (Bacharach et al., 2016; Njiru et al., 2023). The risk is particularly pronounced given the intensification of cage culture in Lake Victoria, which creates open systems that facilitate pathogen exchange between cultured and wild fish (Njiru et al., 2016).

Kenya currently lacks specialized fish diagnostic laboratories recognized by the World Organization for Animal Health (OIE). Disease diagnostics are typically performed at local universities and public research institutions, including Moi, Kenyatta, Egerton, and Maseno Universities, as well as the KMFRI (Africa, 2016). This fragmented diagnostic capacity can delay the response to disease outbreaks, making it difficult to manage fish health effectively (Moges et al., 2024).

In light of the scarcity of fish disease specialists in Kenya, it is essential for aquaculture farmers to adopt preventative measures. These include maintaining optimal environmental conditions for fish, ensuring the stocking of healthy fish, utilizing high-quality feeds, and

minimizing stress to mitigate disease risks in intensive farming systems (Africa, 2016; Karanja et al., 2024). Moreover, there is a growing need for training programs aimed at enhancing the skills of local farmers and technicians in fish health management to improve overall aquaculture sustainability (Moges et al., 2024).

Government initiatives and aquaculture growth

The Economic Stimulus Program (ESP) significantly enhanced fish farming by providing essential resources such as funds for pond construction, inputs like fingerlings and feeds, and technical training for farmers. This reflects the government's commitment to supporting aquaculture as a critical element for food security and economic development in Kenya (KMFRI, 2019; FAO, 2020). As noted, the ESP has catalyzed a marked increase in the number of fish ponds and the area under aquaculture, contributing to the diversification of livelihoods in Uasin Gishu County. However, while the increase in production is commendable, ongoing issues such as limited access to quality feed and disease management persist, limiting the full potential of these initiatives (Musa et al., 2017). The sustainability of such programs requires continuous support and adaptive management strategies that align with the evolving challenges faced by local farmers.

Interpretation of aquaculture production systems

The dominance of semi-intensive systems indicates a balance between resource availability and technological adoption. The fact that over 90% of farmers utilize semi-intensive methods suggests a strong inclination towards a hybrid approach that leverages both natural productivity and supplementary feeding. This finding aligns with global trends, where semi-intensive aquaculture serves as a sustainable compromise between extensive and intensive systems (FAO, 2016). The relatively low percentage of intensive systems (around 3%) highlights significant barriers to entry, such as high energy costs, the need for advanced technologies, and the limited availability of high-quality feeds (FAO, 2020). Addressing these barriers through targeted policies and investments could facilitate the transition of farmers to more intensive and profitable production methods, ultimately enhancing overall productivity and food security (Ogello and Munguti, 2016).

Implications of water quality issues

Water quality remains a critical challenge for fish farmers in Uasin Gishu County, with poor management practices

often leading to oxygen depletion and elevated ammonia levels. These conditions can exacerbate disease outbreaks and significantly reduce productivity, which aligns with findings from Boyd (1998) and Huicab-Pech et al. (2024), who emphasize the importance of maintaining optimal water quality for fish health. The high prevalence of diseases linked to poor water quality indicates a pressing need for better management practices and the adoption of innovative technologies such as recirculating aquaculture systems (RAS). The successful implementation of RAS could mitigate many of these water quality issues by allowing for better control over water parameters and reducing waste accumulation (Timmons and Ebeling, 2010). Moreover, improving water quality management practices could lead to enhanced fish growth rates, higher survival rates, and overall better farm profitability (Mbugua, 2008).

CONCLUSIONS AND RECOMMENDATIONS

Aquaculture in Uasin Gishu County has experienced notable growth but faces ongoing challenges related to sustainability, water management, and disease control. To ensure long-term viability, future efforts must focus on improving access to quality feed, enhancing water management practices, and adopting new technologies such as recirculating systems. Further research is necessary to understand the impacts of climate change on local aquaculture and to develop region-specific solutions.

FUTURE RESEARCH DIRECTIONS

The results of this review suggest several avenues for future research. Firstly, longitudinal studies that assess the long-term impacts of government initiatives like the ESP on fish farming productivity and sustainability would provide valuable insights (Karanja et al., 2024). Additionally, research focusing on the integration of aquaculture with agricultural practices (such as, integrated aquaculture-agriculture systems) could yield innovative solutions to optimize resource use and enhance farm resilience (Ogello et al., 2013). Exploring the impacts of climate change on water availability and quality will also be critical, given the potential challenges posed by changing environmental conditions (FAO, 2020). Lastly, studies investigating the socio-economic factors influencing farmer decisions regarding aquaculture practices will be essential to develop targeted interventions that address local needs and capabilities (Adeleke et al., 2020).

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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