European Journal of Science, Innovation and Technology
ISSN: 2786-4936
www.ejsit-journal.com
Volume 5 | Number 6 | 2025

Forecasting the Emerging Risks of Aquaculture Growth in the One Health Lens in the Zambezi's Kafue Basin, Zambia

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ABSTRACT

Aquaculture has emerged as one of the fastest-growing food production sectors globally and it is increasingly being promoted in Zambia as a strategy to improve food security and health nutrition, provide employment, and reduce pressure on capture fisheries. The Kafue Basin, a sub-basin of the Zambezi River system, is a highly productive yet ecologically sensitive landscape where aquaculture expansion is occurring alongside multiple competing water uses. This paper presents an expert-informed synthesis of perpectives drawing on previous empirical research and postgraduate thesis findings to examine the environmental, socio-economic, and governance risks associated with the expansion of both commercial and small-scale aquaculture in the basin through a One Health lens. Integrating hydrological, ecological, livelihood, and aquatic animal health perspectives, the analysis highlights nutrient pollution, degradation of wetland integrity, disease transmission, genetic risks, competition over water resources, and livelihood conflicts as key emerging threats, particularly in contexts of weak regulation. The paper further proposes practical mitigation strategies and policy recommendations informed by experiences from comparable river basins, emphasizing the importance of integrated basin planning, community participation, adaptive management, and cross-sectoral governance to support sustainable aquaculture development while safeguarding human, animal, and environmental health in the Zambezi's Kafue Basin, Zambia.

Keywords: Aquaculture; Food systems; Fish; Biosecurity risks; Wetlands; Environment; Kafue Basin; Policy; One Health

INTRODUCTION

Aquaculture has become central to global food systems, now supplying nearly half of all fish consumed worldwide (FAO, 2020; Bouwmeester et al., 2021). Its rapid growth is driven by population increases, nutritional value of fish, urbanization, and the decline of capture fisheries (Miller et al. 2008; Troell et al., 2014; Boyd et al., 2020; Campanati et al., 2021; Xu et al., 2024a). In Zambia, aquaculture is promoted by several projects such as the Zambia Aquaculture Enterprise Development (ZAEDP), as a pathway to food security, rural employment, and economic diversification. In Zambia's Kafue basin, aquaculture is increasingly considered a solution to declining wild fish stocks and growing protein demand.

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While aquaculture can enhance, provide employment, food security and economic development, its expansion in sensitive areas like the Kafue Flats poses environmental, genetic, and social risks. Expansion of small enterprises fish farming or commercial aquaculture here risks undermining species biodiversity integrity, altering hydrological regimes, and creating social tensions. These risks extend beyond production systems and intersect with human, animal, and ecosystem health, thus making aquaculture a fundamental “One Health” issue.

One Health is an integrated and unifying approach that recognizes that human health, animal health, and ecosystem health are intrinsically interconnected and interdependent. It emphasizes that many contemporary health and sustainability challenges such as emerging infectious diseases, food safety risks, antimicrobial resistance (AMR), and environmental degradation arise from interactions across these domains and therefore cannot be effectively addressed through single-sector approaches (Zinsstag et al., 2011). The One Health framework promotes interdisciplinary and cross-sectoral collaboration among human health, veterinary, environmental, and social science disciplines to improve health outcomes while safeguarding ecosystem integrity (Destoumieux-Garzón et al., 2018). Beyond a technical concept, One Health also represents a governance and policy lens that draws attention to power relations, institutional coordination, and equity in the management of shared health risks (Hinchliffe, 2015; Craddock & Hinchliffe, 2015; Brandão et al., 2021).

In aquatic and aquaculture systems, One Health is particularly relevant because environmental change, aquatic animal disease, and human well-being are tightly coupled through shared water resources, food systems, and livelihoods. Degradation of water quality, disease transmission between farmed and wild fish, and loss of ecosystem services can directly affect food security, nutrition, and community health, making aquaculture development a clear One Health concern. Poorly planned development can undermine species biodiversity integrity, alter hydrological regimes of the Kafue and its tributaries, facilitate pathogen transmission between farmed and wild fish, and generate social tensions that affect community well-being.

This paper synthesizes perspectives on ecological, hydrological, and socio-economic evidence to critically examine these risks and propose mitigation strategies. The paper builds strongly on previous empirical findings (Nkhoswe et al., 2023) to critically examine these risks and propose mitigation and policy interventions. The One Health framework is used as a lens to systematically connect environmental processes, aquatic animal health dynamics, and human well-being outcomes associated with aquaculture expansion. The objective is therefore not hypothesis testing, but problem framing, risk identification, and conceptual integration, which are widely accepted aims of opinion-based and perspective-oriented scholarly contributions (Hinchliffe, 2015; Fazey et al., 2018; Snyder, 2019).

MATERIALS AND METHODS

Description of the Study Area

The Kafue River is Zambia’s longest river lying entirely within national borders and constitutes one of the country’s most critical socio-ecological systems. Stretching for approximately 1,300 km in length, the Kafue River descends from an elevation of 1,395 m at its source to 359 m where it meets the Zambezi River – which is shared by more than five countries. Along its course, several significant tributaries feed into the Kafue River, including the Lunga, Kofuku, Luswishi, Lufupa, Kafulafuta, Kaleya, and Mwembeshi. Hence, the Kafue basin itself is the largest sub-system of the Zambezi River catchment.

The Kafue basin is one of the six major hydrological catchments in Zambia. It spans the area between approximately 24°42'–28°30' East and 11°30'–17°30' South, covering about 156,034 km², which accounts for approximately 20 percent of the country’s total land area, WARMA (2022) reports.

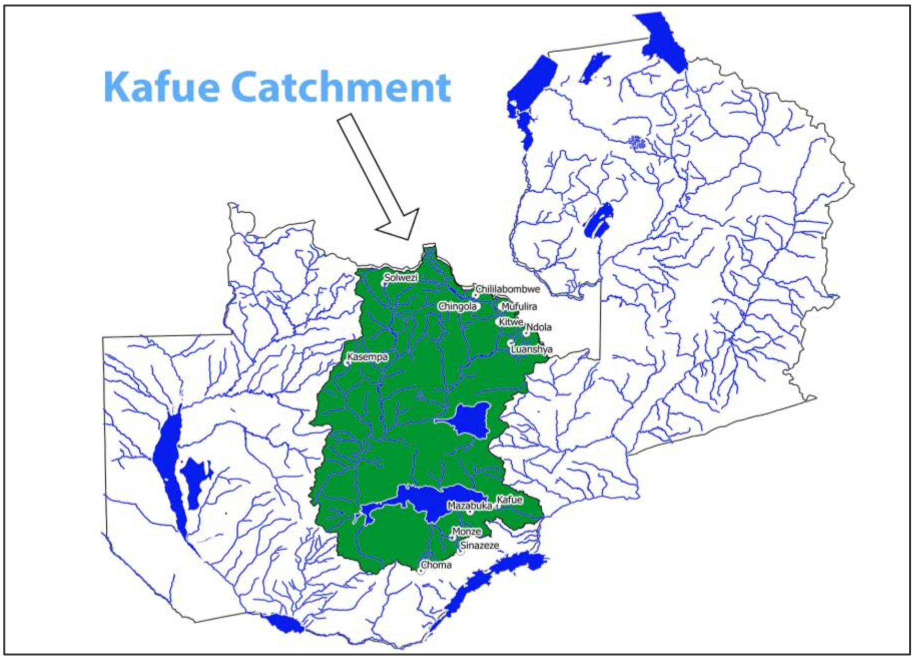

Figure 1: Map of Zambia showing the Kafue basin with interconnected river systems (WARMA, 2022)

These tributaries are vulnerable to impacts associated with expanding aquaculture activities. If insufficiently regulated, operations may for instance facilitate the spread of invasive species.

The Kafue River supports a large proportion of Zambia's population through its provision of irrigation water, hydroelectric power generation, domestic water supply, and biodiversity-rich landscapes such as the Kafue Flats and Kafue National Park in its basin (WARMA, 2022). The Kafue Flats (fertile floodplains) which form part of the wider Kafue Basin are endowed with a great biodiversity of wildlife in the Kafue wetlands Ramsar site and abundant water resources (Ramsar Convention Secretariat, 2008). These multiple ecosystem services make the Kafue River indispensable to rural livelihoods, urban economies, and national development planning, thus raising the sensitivity of any socioecological and economic activity being introduced to the system such as aquaculture.

Methodological Approach and Scope

This study adopts a conceptual, integrative, and expert-informed analytical approach, consistent with the conventions of opinion, perspective, and synthesis papers addressing complex social–ecological challenges. Rather than employing primary data collection, the analysis is grounded in the authors' domain-specific expertise in fisheries, aquaculture, wetland ecology, and water governance in the Kafue Basin, combined with a structured synthesis of peer-reviewed literature, policy documents, and technical reports. Such approaches are widely recognized as methodologically valid for examining emerging risks, system interactions, and governance gaps where empirical data may be fragmented or where problems span multiple sectors and scales (Zinsstag et al., 2011; Fazey et al., 2018).

Both commercial and small-enterprise aquaculture systems were considered within the scope of this analysis in order to capture the diversity of production practices emerging in the Kafue Basin. The assessment encompasses a range of aquaculture modalities, including earthen pond-based fish farming, cage aquaculture in open water bodies, flow-through raceway systems, aquaponic systems that integrate fish production with plant cultivation (which discharge aquaculture effluents into the crop farms), and recirculating aquaculture systems (RAS) designed to minimize water use and effluent discharge.

Expert knowledge and integrative synthesis play a critical role in sustainability science, particularly in identifying early warning signals, articulating cross-sectoral linkages, and framing policy-relevant questions that cannot be addressed through single-disciplinary or single-method studies (Cash et al., 2003; Raymond et al., 2010). By examining these systems collectively, the study reflects the varied technological, environmental, and management contexts in which aquaculture expansion is occurring and allows for a comparative understanding of their potential risks, benefits, and governance implications.

Limitations of the Approach

As an expert-informed and conceptual contribution, this paper does not present empirical data derived from primary field measurements or experimental designs. Consequently, the magnitude and direction of specific impacts associated with aquaculture expansion in the Kafue Basin cannot be quantitatively assessed, nor can causal relationships be statistically tested.

The analysis is also influenced by the availability and quality of existing literature and policy documentation, which may be uneven across sectors and spatial scales. Nevertheless, the purpose of this approach is not prediction or generalization, but problem framing, synthesis, and identification of emerging risks and governance gaps within a complex social–ecological system. Future research would benefit from targeted empirical studies such as water quality monitoring, disease surveillance, and socio-economic assessments to validate and refine the conceptual insights presented here.

SYNTHESIS: RISKS OF AQUACULTURE GROWTH IN THE KAFUE BASIN

Water Pollution and Eutrophication Risks

The Kafue wetlands are under stresses from hydropower dams, cattle ranching and agriculture (Chabwela et al., 2018; Cowx et al., 2018). Aquaculture intensification often results in nutrient enrichment of surrounding waters. Unconsumed feed and fish excreta introduce nitrogen and phosphorus, which stimulate eutrophication, algal blooms, and oxygen depletion (Beveridge, 2004; Boyd et al., 2020; Naylor et al., 2021). In floodplain systems like the Kafue Flats, nutrient hotspots can persist due to sediment accumulation beneath cages and ponds especially after precipitation followed by nutrient flushing into the open environment or after the effluents were irrigated into crop farms. These changes threaten water quality, fisheries productivity, and ecosystem services such as flood regulation and carbon sequestration. Without effective effluent management, aquaculture is an emerging threat that can accelerate degradation of one of Zambia’s most important wetlands, the Kafue flats.

Disease and Parasite Transmission

High-density fish farming creates conditions conducive to pathogen outbreaks. Viral, bacterial, and parasitic infections can spread rapidly within farms and spill over into wild populations (Johansen et al., 2011; Krkošek et al., 2013). Such outbreaks compromise food security, increase production costs, and necessitate costly biosecurity measures.

In the Kafue Basin, where wild and farmed fish interact closely, disease risks are particularly acute. The lack of adequate training to many fish farmers (Nkhoswe et al., 2023), especially those who are new to the activity are at high risks of spreading zoonotic diseases. The improper use of antibiotics such as ciprofloxacin, erythromycin, and azithromycin in aquatic farms, without veterinary guidance or correct training on admission and disposal, further risks the advancement of antimicrobial resistance (AMR) and hormonal pollutants in the Kafue catchment, like it was reported by studies in Bangladesh (Debnath et al., 2023).

Genetic Risks from Farmed Fish Escapes

Flood-prone systems increase the likelihood of farmed fish escaping into natural waters. Escaped fish may interbreed with wild populations, leading to genetic introgression, reduced diversity, and loss of local adaptations (Neff et al., 2011; Lorenzen et al., 2012; Ansah et al., 2014; Glover et al., 2017). These risks threaten the long-term sustainability of capture fisheries and undermine conservation goals. In the Kafue Flats, where seasonal floods are common, escape prevention must be prioritized.

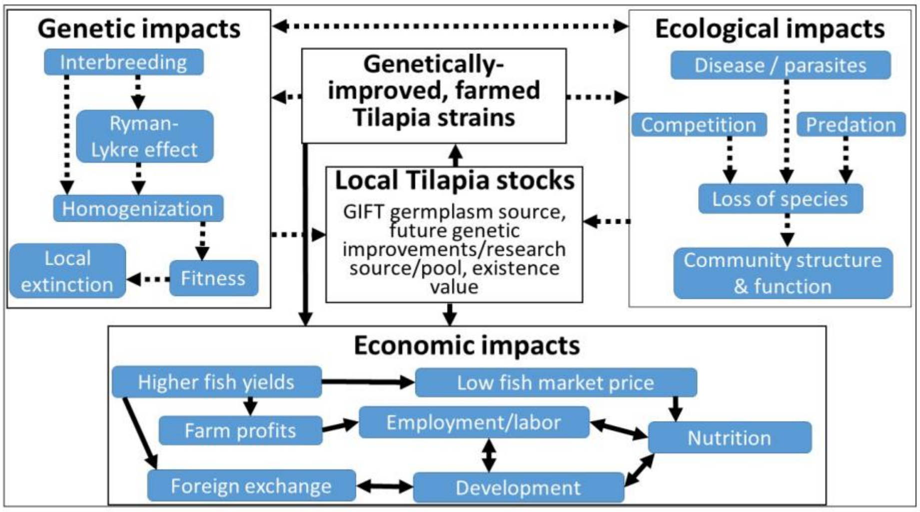

Figure 2: Interconnected potential ecological, genetic, and economic consequences arise from the introduction of genetically improved tilapia (GIFT) into Africa

Broken arrows conceptually represent negative pathways of impact, while solid arrows denote positive linkages (Ansah et al., 2014)

Socio-Economic Impacts and Livelihood Risks

Risks associated with aquaculture development are often intensified by weak governance, environmental externalities, and the unequal distribution of benefits, which disproportionately affect vulnerable communities and traditional livelihoods (Béné et al., 2007; Cleaver & De Koning, 2015). The socio-economic conditions of local youth can be negatively impacted in the Kafue Basin, where commercial aquaculture centers are established. For example, sudden income opportunities may lead to risky behaviors such as substance abuse or exploitative relationships, while the recruitment of young workers from other provinces can generate tensions and conflicts with local communities (Ratner et al., 2014).

In addition, commercial aquaculture can restrict artisanal fishers' access to traditional fishing grounds, reducing income and food security (Haller & Chabwela, 2009). Thus, unequal benefit distribution may exacerbate social conflict and marginalize vulnerable groups, particularly women and youth. Without inclusive governance, aquaculture risks deepening inequality rather than alleviating poverty.

Land-Use Conflicts and Governance Challenges

Conversion of customary lands, wetlands and floodplain lands to privatized lands for commercial use such as aquaculture farms often sparks disputes under customary tenure systems (Adams et al., 2004; Haller & Chabwela, 2009). Weak regulatory enforcement and fragmented governance exacerbate these risks (FAO, 2018; World Bank, 2013). Transparent land-use planning and participatory governance can prevent such conflicts in the Kafue Basin.

Competition for Water Resources and Increased Energy Demands

Aquaculture depends heavily on freshwater resources, often competing with hydropower generation, irrigation, and domestic consumption (FAO, 2018). In Zambia's Kafue Basin, where hydropower availability remains constrained and intermittent periodic load-shedding persists, large-scale aquaculture further intensifies demand by requiring substantial energy inputs for pond management, and breeding facilities. This overlap risks exacerbating competition with household electricity supply. To mitigate such pressures, integrated water-resource management is essential to balance aquaculture alongside other sectors. At the same time, diversifying energy sources—particularly through solar power—can provide a more resilient foundation for aquaculture expansion. Without these measures, the Kafue Basin is likely to face heightened competition over hydropower between domestic users and industrial sectors such as mining, crop agriculture, and the growing aquaculture sector.

Disappearance of "Sponge Towns" in the Kafue Basin

The ecological productivity of the Kafue Flats depends on seasonal flooding, and groundwater recharge. This sustains fish spawning, wildlife and cattle grazing, and nutrient cycling. Grey infrastructure in the catchment, especially near the Kafue River and its tributaries can obstruct water flow, fragment habitats, and reduce connectivity between floodplain lagoons. Through a catchment scale lens, the establishment of aquaculture facilities in the Kafue Basin introduces additional hydrological and ecological pressures to an already populated landscape.

Increased settlement of employees (for hatcheries and merchants along the aquaculture value chains) intensifies demand for land, water, and infrastructure, compounding existing alterations near wetlands caused by upstream hydropower dams, impoundments, and the sealing of surfaces through industrial and residential development (Schneider et al., 2017). These cumulative changes destabilize groundwater tables, reducing recharge moisture and degrading wetland functionality (Zeng et al., 2024). The absence of integrated "sponge city" planning around aquaculture hubs limits infiltration of precipitation, thereby altering both surface runoff and subsurface hydrology (DCCEEW, 2023). Over time, such pressures undermine biodiversity conservation and threaten the ecological integrity of Ramsar-listed wetlands in the basin, which depend on stable hydrological regimes for sustaining species and ecosystem services (Labra & Jaramillo, 2024).

AQUACULTURE AND THE ONE HEALTH CONCEPTUAL FRAMEWORK

Building the Aquaculture-One Health framework

Aquaculture development in freshwater systems such as the Kafue Basin influences water quality, ecological processes, and disease dynamics in ways that extend beyond fish production alone. We emphasize that while expanded aquaculture can contribute to food availability and nutritional security, it also has the potential to generate interconnected risks across human, aquatic animal, and environmental health domains, particularly where biosecurity, environmental management, and governance are limited.

Accordingly, aquaculture development in the Kafue Basin is conceptualized in this study through a One Health framework that explicitly connects human health, aquatic animal health, and environmental integrity. From this perspective, aquatic animal health serves as a key interface linking environmental change and human well-being. Disease emergence, genetic stress, and reduced productivity in cultured and wild fish populations may arise from declining water quality, habitat alteration, and intensified production practices, with cascading implications for livelihoods, food safety, and community resilience.

A One Health framing therefore provides an integrative lens for understanding how aquaculture expansion in the Kafue Basin can simultaneously generate benefits and unintended cross-sectoral trade-offs. This framework provides the basis for the subcomponents presented below, which detail the pathways through which aquaculture-related activities influence health and sustainability outcomes across these interconnected domains.

Human Health Component

- Improved nutrition and food security through increased availability of fish protein
- Potential exposure to waterborne pathogens, antimicrobial residues, and toxins associated with harmful algal blooms
- Social well-being shaped by equity, livelihood security, conflict, and access to aquatic resources

Aquatic Animal Health Component

- Transmission of infectious diseases between cultured and wild fish populations
- Genetic introgression from farmed strains into wild stocks, potentially reducing local adaptation and resilience
- Stress, reduced growth, and increased mortality associated with declining water quality and habitat alteration

Environmental Health Component

- Nutrient enrichment, eutrophication, and deterioration of water quality
- Habitat modification and hydrological disruption within a Ramsar-listed wetland system
- Cumulative impacts arising from cage density, feed inputs, effluent discharge, and infrastructure development

Figure 3: The conceptual illustration of the One Health framework as applied to aquaculture expansion in the Kafue Basin, Zambia (Nkhoswe et al., 2025)

The developed conceptual diagram highlights the overlapping domains of human health, aquatic animal health, and environmental health, and illustrates how aquaculture-related pressures such as nutrient loading, disease transmission, genetic interactions, and water-use competition operate at their intersections. The central overlap emphasizes that aquaculture outcomes in the Kafue Flats emerge from the interaction of these domains rather than from any single pathway. By visualizing these linkages, the figure provides an integrative lens for identifying leverage points for policy and management, including biosecurity measures, spatial planning, water governance, and community engagement. This One Health framing reinforces the argument that sustainable aquaculture in the basin requires coordinated, cross-sectoral governance approaches capable of addressing complex and interconnected risks.

MITIGATION STRATEGIES (POLICY RECOMMENDATIONS)

Site Selection and Buffer Zones

The location of aquaculture facilities is one of the most critical determinants of environmental impact. Welch et al. (2019) demonstrated that when offshore aquaculture facilities are carefully located, appropriately scaled, and efficiently managed, their environmental impacts are minimal. Modern tools such as GIS-based suitability analysis and seasonal flood mapping can help identify low-risk zones and guide mandatory buffer strips along channels. Riparian buffers have been shown to reduce nutrient transfers and preserve ecosystem services, though their effectiveness depends on vegetation type and width (Sweeney & Newbold, 2014). A hot debate persists around "blue growth" as proponents argue that aquaculture can coexist with conservation through zoning, while critics highlight cumulative impacts and regulatory gaps that undermine Ramsar commitments (Soto et al., 2008; Tett, 2017; Brugère et al., 2019).

Closed or Semi-Closed Systems and the WEF-Nexus Agenda

Recirculating aquaculture systems (RAS) and lined ponds with controlled discharge are increasingly being promoted as solutions to reduce effluent and escape risks. Reviews highlight their ability to meet stringent water-quality standards and lower nutrient footprints per unit of biomass (Martins et al., 2010; Badiola et al., 2012). However, RAS are energy-intensive and capital-heavy, raising questions about their sustainability in low-resource contexts. Considering that Zambia's primary electricity utility, ZESCO Limited (Zambia Electricity Supply Corporation), is increasingly constrained by limited generation capacity, the expansion of energy-intensive aquaculture systems presents a significant socio-economic challenge. Life-cycle assessments indicate that the environmental and climate impacts of an activity depend strongly on energy sources and system design (Jerbi et al., 2011; Henriksson et al., 2012). In this context, reliance on grid electricity for commercial aquaculture, rather than alternative energy sources such as solar power, could intensify competition for energy, exacerbate emissions, and undermine the sustainability of aquaculture expansion.

Semi-closed lined ponds may offer a more affordable compromise, provided technical support is available. The debate centers on whether RAS represents a "green" solution or a technology that risks excluding smallholders without targeted policy support like the Farmer Input Support Programme (FISP), which is for crop farmers. The adoption of WEF-nexus agenda in the planning would aid in synergies and tradeoffs for hydropower energy and water usage for aquaculture in the Kafue.

Best Management Practices for Feed and Waste

Nutrient control in aquaculture hinges on feed quality, feeding efficiency, and effluent treatment. High-quality, digestible feeds and precision feeding technologies such as automatic feeders and feed-conversion tracking, and polyculture, reduce waste and nutrient outputs (Bostock et al., 2010; Glencross et al., 2025). Beyond feed optimization, sediment traps, vegetated buffers, settlement basins, and constructed wetlands intercept solids and transform dissolved nutrients before discharging them into free-flowing water systems.

Fish farmers in the Kafue should be encouraged, based on empirical studies, to reduce suspended solids and nitrogen/phosphorus loads by via such systems (Peng et al., 2012; Amponsah et al., 2024; Arturo et al., 2024; Xu et al., 2024b; Corso et al., 2025). The debate sparked is largely about trade-offs: constructed wetlands require land and maintenance, while high-performance feeds are costly, raising equity concerns for small-enterprise holders unless subsidies or technical support (extension services) are provided. In the Kafue Basin, this might be a significant problem as the small-holder fish farmers are in higher number (FAO, 2018) than the commercial fish farmers.

Biosecurity and Health Management Training and Monitoring Programs

Biosecurity measures are critical to prevent pathogen amplification and spillover. Farm registration, routine health screening, trainings by extension officers, stiff movement of broodstock or fingerlings controls, vaccination, quarantine, and rapid reporting systems form the backbone of effective disease management. Comparative studies show that standardized surveillance and movement regulation reduce outbreak frequency and economic losses (Murray & Peeler, 2005; Jones et al., 2015; WOAH/OIE, 2021). This provides an evidence-based direction in which aquaculture governance in the Kafue Basin should be driven towards.

To lower the chances of antimicrobial resistance, fish farming should use antibiotics carefully and responsibly. Farmers should also look for other options besides antibiotics and focus on preventing diseases before they spread (Defoirdt et al., 2011; Bondad-Reantaso et al., 2023). The debate revolves around acceptable stocking densities and prophylactic treatments: producers emphasize cost and feasibility, while public-health perspectives argue for precautionary thresholds in ecologically sensitive basins such as this Zambezi sub-basin.

Genetic Management and Prevention of Farmed Fish Escapes

Restricting non-native or genetically improved strains in high-connectivity waters, coupled with secure cage design and flood-resistant moorings, reduces introgression risks. Evidence shows that interbreeding with domesticated strains reduces fitness and local adaptation in wild populations and that breeding programs in aquaculture set-ups rarely uphold the genetic adaptations and fish species diversity (Karlsson et al., 2011; Neff et al., 2011; Glover et al., 2017).

Using verified local broodstock and genetic screening helps maintain population structure, while physical measures such as double netting and flood contingency planning lower escape probabilities (Lorenzen et al., 2012). The debate is polarized: advocates of improved strains highlight productivity gains, while conservationists warn of irreversible genetic impacts in gene hybridizations of riverine fish metapopulations (Ansah et al., 2014; Wringe et al., 2018; Atalah & Sanchez-Jerez, 2020; Sanda et al., 2024). It should be mandated that both commercial and small-holder fish farmers have this knowledge via certification.

Co-management and Benefit Sharing

Co-management frameworks that reserve shoreline access, establish committees with artisanal fishers, and mandate benefit-sharing agreements can reduce marginalization and conflict. Studies show that co-management improves compliance and equity when institutions are empowered and benefits are tangible (Jentoft, 2000; Béné et al., 2007; Berkes, 2009). In floodplain contexts, community fisheries and smallholder cooperatives have enhanced food security, while large commercial projects without safeguards have exacerbated exclusion, reported Haller & Chabwela (2009) in the Kafue Flats.

The debate is whether co-management genuinely redistributes power or merely provides procedural inclusion. Evidence suggests enforceable benefit-sharing clauses and recognition of customary rights are critical to achieving meaningful equity (Cleaver & De Koning, 2015).

CONCLUSIONS

Aquaculture offers significant opportunities for food security and economic development in Zambia. However, in ecologically sensitive systems such as the Kafue Basin, its expansion commercially carries substantial environmental, genetic, social, and institutional risks while posing debatable tradeoffs and synergies when examined through the WEF-nexus lens and the One Health framework. The cumulative effects of nutrient loading, habitat alteration, disease spread, genetic risks, and social conflict threaten both aquaculture and capture fisheries sustainability as well as human health to the consumers due to zoonosis and bioaccumulation processes. In the One Health lens, aquaculture outcomes in the Kafue Flats emerge from dynamic interactions across human, animal, and environmental health domains. By explicitly recognizing these interconnections, One Health–aligned governance offers a pathway toward aquaculture development that is not only productive and resilient, but also ecologically resilient and socially just. Without precautionary management, aquaculture could undermine the very food security it seeks to enhance.

This paper has demonstrated that both commercial and small-enterprise aquaculture development, if poorly planned and weakly regulated, could exacerbate existing pressures on the Kafue Flats and undermine both livelihoods and ecosystem services. Sustainable aquaculture in the Kafue Basin therefore depends on precautionary planning, strong governance, community participation, and basin-wide integration of water and land management. Without such measures, aquaculture expansion risks becoming a driver of ecological degradation of this Zambezi sub-basin rather than a pathway to sustainable development for alternative livelihoods and biodiversity promotion. We thus conclude that One Health framework enables the identification of critical leverage points for policy and management, such as biosecurity regulation, spatial planning, water governance, and community engagement, which can reduce risks while enhancing co-benefits.

CONFLICT OF INTEREST

The authors declare that this work was conducted in the absence of any commercial or financial relationships that could be seen as a potential conflict of interest. This communication paper builds upon and extends empirical insights generated through the lead author's postgraduate research conducted in the Kafue Basin, Zambia. The postgraduate study was undertaken at the University of Zambia (UNZA) and completed under the auspices of UNESCO-IHE (now IHE Delft Institute for Water Education), The Netherlands.

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