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Unlocking potential: an assessment of small-scale aquaculture viability in the Lake Victoria Basin, Uganda

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Abstract
Despite small-scale pond aquaculture being a vital component of the Lake Victoria Basin communities, its viability is not known. In this study, we examined the viability of small-scale pond aquaculture in the districts of Mpigi, Buikwe, and Wakiso in Uganda, focusing on social-economic and technical aspects. Employing a mixed-methods approach, including household surveys and focus group discussions with 169 fish farmers, the study assessed the effectiveness and sustainability of small-scale pond aquaculture in 2023. Despite challenges such as market access, low input quality, and environmental impacts, small-scale pond aquaculture is economically viable and plays a crucial role in fish production. The Buikwe and Wakiso districts demonstrated greater productivity and efficiency than did the Mpigi district, with notable variations in fish production and pond sizes. The study further highlights the need to improve market access, input quality, and income diversification through targeted interventions within the basin. Additionally, efforts should be made to optimize technical practices such as pond management, efficient feed management, optimal stocking and harvesting techniques as well as disease management and biosecurity.

Keywords Small-scale pond aquaculture · Viability · Lake Victoria Basin · Fish production · Uganda

1 Introduction

Small-scale aquaculture and capture fisheries are deeply embedded in the cultural and economic fabric of the Lake Victoria Basin communities, playing a pivotal role in household food security and livelihoods [1, 2]. The Lake Victoria Basin, a fish-consuming region in Uganda, boasts annual per capita fish consumption of over 12.5 kg [3], surpassing the African average of 10.1 kg per capita [4]. This reflects the essential role fish play in local diets and nutrition. In Uganda, fish contribute approximately 4.3 g of protein per capita per day [3], marking them as a primary source of animal protein for nearly half of the population [5]. The primary species contributing to this production are catfish and Nile tilapia, which together account for approximately 50% in the region, with 51% of the catfish population and 49% of the Nile tilapia population [6]. The dominance of these species stems from their adaptability to local environmental conditions and their considerable contribution to both household nutrition and the local economy. Small-scale pond aquaculture has emerged as a viable and sustainable means to supplement fish supplies, meeting the high local demand while supporting livelihoods in the region [1, 2]. Capture fisheries and aquaculture in the region rely on the rich ecosystems

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provided by water bodies, wetlands, and ponds around Lake Victoria and along riverbanks [7]. These environments are crucial breeding grounds and habitats for diverse fish stocks [8], with migration patterns, such as those from the upper reaches of the Nile River, being particularly important [9]. This interconnectedness of water systems facilitates the natural spawning and growth of fish populations, supporting both local fisheries and livelihoods [5, 10]. Although natural fish stocks in Lake Victoria have declined, recent decades have seen an increase in total fish catches in central Uganda [10]. However, this rise has not kept pace with population growth, leading to reduced catch quality and quantity per fisher, driven by competition for limited resources [3]. Illegal fishing exacerbates the strain on wild fish populations, posing a significant threat to the region's vital protein source [10]. These challenges raise concerns about the sustainability of Lake Victoria's ecosystems to meet growing fish demand [3]. While lake water cage culture, which involves raising fish in submerged cages within natural water bodies such as lakes, accounts for more than half of the region's aquaculture production [11], this paper exclusively focuses on smallholder pond aquaculture. Smallholder pond aquaculture refers to fish farming in artificial or natural ponds, managed primarily by small-scale producers, which contributes approximately 22% of total yield [12]. Despite its smaller share, smallholder pond aquaculture plays a crucial role in supporting livelihoods and meeting local demand. This sector, while modest in scale, is expanding rapidly, reflecting the broader growth of aquaculture within the basin. Aquaculture now accounts for 30% of total fish production, a significant increase from previous levels, with average annual growth rates of over 14% between 1990 and 2018 and exceeding 19% between 2006 and 2020 [3]. Small-scale pond aquaculture offers substantial economic benefits, contributing to poverty alleviation and providing steady income streams [12]. Studies highlight its potential for income generation, particularly through the cultivation of high-demand species like tilapia and catfish, which have relatively low start-up costs [13]. Compared to traditional agriculture, aquaculture often yields a greater return on investment, making it attractive for smallholder farmers [14]. However, challenges like limited access to quality inputs and market fluctuations affect profitability [15]. In addition to economic benefits, aquaculture improves food security by providing a reliable source of protein [2], while also creating employment opportunities, particularly for women and youth [16]. Community-based aquaculture initiatives promote cooperation and social cohesion [8], though concerns about equitable distribution of benefits and resource conflicts persist [17]. Environmental sustainability is another key consideration. Small-scale pond aquaculture can reduce overfishing pressure on wild stocks [18] and often employs sustainable practices like recirculating or integrated systems [19]. However, poorly managed systems can lead to negative environmental impacts such as water pollution and habitat degradation [20]. Effective management practices and regulatory frameworks are critical to minimizing these risks and ensuring sustainable development [21]. The aquaculture sector's growth has been driven by advances in hatcheries, feed production, and disease management [18]. However, many small-scale farmers still face technical challenges, limited access to quality inputs, and insufficient training [22]. Addressing these issues is essential to improving productivity and efficiency [18]. Moreover, market access remains a challenge, with fluctuating prices and competition from wild-caught fish impacting small-scale producers [15]. Ultimately, small-scale pond aquaculture holds significant potential to improve household earnings and reduce poverty by providing alternative income sources and enhancing food security. However, its success depends on several factors, including market access, technical support, and effective resource management. Environmental challenges, such as water scarcity and flooding, particularly in regions with distinct climatic seasons, also play a role in determining its viability [23, 24]. Uganda's strategy for equitable agricultural development recognizes these challenges and emphasizes the importance of aquaculture in enhancing food security and poverty reduction [3]. In response to these challenges, the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) has launched initiatives to promote small-scale pond aquaculture, including cage culture, aquaponics, and semi-intensive pond management [25, 26]. These programmes, implemented in stages across three districts, provide critical inputs and technical support to smallholder farmers, aiming to enhance productivity and sustainability [3, 27]. Despite the growing recognition of aquaculture's potential, it remains underexplored compared to smallholder agriculture [28, 29]. This study addresses this gap by investigating the viability of small-scale pond aquaculture in the Lake Victoria Basin, Uganda. The aim is to provide evidence-based recommendations that address the economic and technical factors critical to the success of smallholder pond aquaculture in supporting local livelihoods and food security.

1.1 Conceptual framework of the study

Figure 1 presents our study's conceptual framework, illustrating how various variables influence the viability of small-scale pond aquaculture in the Lake Victoria Basin, Uganda. Access to hatcheries provides essential high-quality fingerlings, enhancing fish survival rates and growth, which directly affects the economic viability of aquaculture [30, 31]. Input

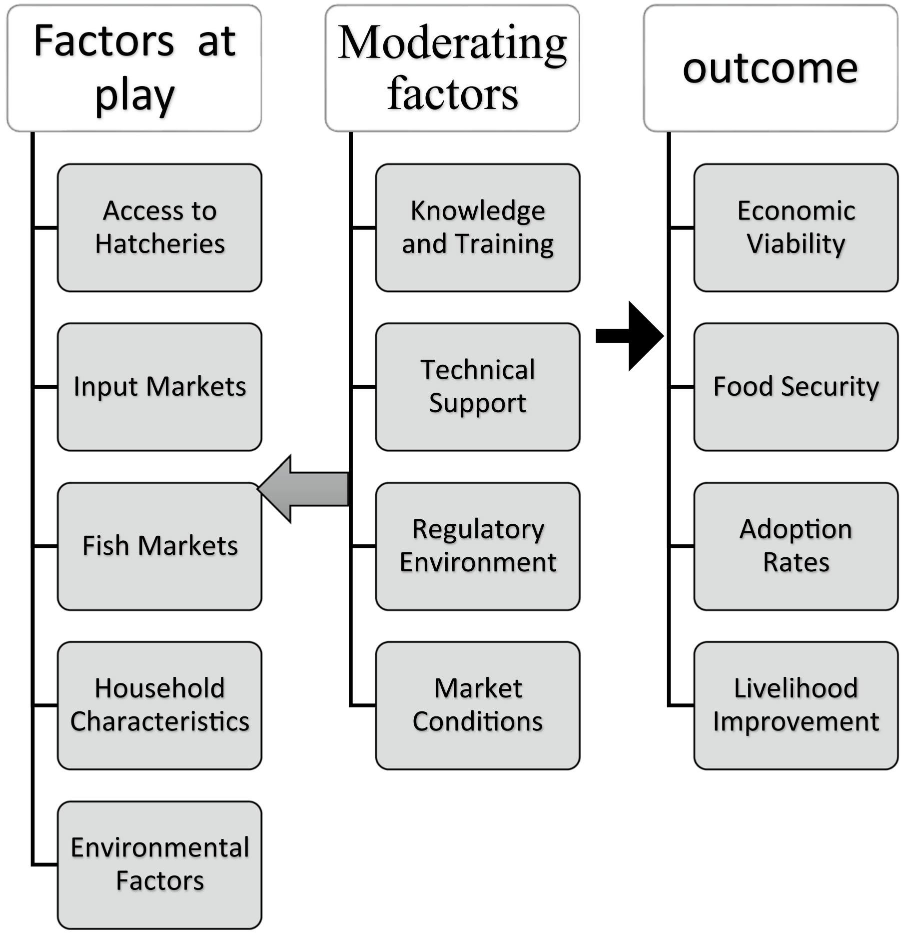

Fig. 1 Study conceptual framework

markets facilitate the availability of crucial resources such as feed and equipment, thus reducing operational costs and boosting productivity [14].

Fish markets ensure reliable outlets for selling fish, impacting food security and livelihood improvement [21, 32]. Household characteristics, including education, skills, and secure land tenure, influence the viability and success of aquaculture practices [33, 34]. Environmental factors such as water quality are crucial for fish health and profitability [35, 36]. Knowledge and training improve management practices and economic viability [37, 38], while technical support helps in implementing best practices [39, 40]. A supportive regulatory environment and stable market conditions create a favorable framework for aquaculture growth [11, 39, 41]. Ultimately, these factors contribute to economic viability, food security, viability rates, and livelihood improvement [42–45].

In Uganda, access to hatcheries is limited, resulting in reduced fish survival rates and growth potential, which hinders the viability of small-scale aquaculture [25, 46]. Enhancing hatchery quality and availability is crucial for boosting production and profitability. Additionally, input markets face challenges like inadequate feed supply chains and high costs, which increase operational expenses for farmers; improving access to affordable, high-quality inputs can enhance productivity [47, 48]. Fish markets are often informal, with poor infrastructure and price volatility hindering market access and income stability for small-scale farmers [21, 49]. Household characteristics such as low literacy rates, lack of formal aquaculture training, and insecure land tenure further constrain viability [33, 50], underscoring the need for tailored capacity-building and land reforms. Environmental challenges in the Lake Victoria Basin, such as water pollution and climate variability, negatively impact fish health and yields, necessitating better water management practices [50, 51]. Moreover, localized training programs and expanded technical support services are essential for farmers to implement best practices [38, 40]. Lastly, while Uganda has policies to support aquaculture, weak enforcement and unstable market conditions hinder sector growth, making stronger regulatory frameworks and market stability critical for the expansion of small-scale aquaculture [11, 41].

1.2 Theoretical framework of the study

Our study is guided by the diffusion of innovations theory developed by Everett Rogers. This theory provides a robust framework for understanding how new technologies and practices spread among individuals and communities, making it particularly relevant for studying small-scale pond aquaculture in the Lake Victoria Basin. It explains how and why new aquaculture practices, such as advanced fish breeding techniques or sustainable farming methods, are adopted by farmers. The theory highlights key factors influencing viability, including relative advantage, compatibility, complexity, and observability. For instance, practices that offer clear benefits over traditional methods (relative advantage) and those that integrate well with existing methods (compatibility) are more likely to be adopted. Additionally, innovations that are easier to understand and implement (complexity) and those that produce visible results (observability) tend to have higher viability rates [52]. Brummett et al. [10] and Kumar and Engle [53] discuss the role of innovation diffusion in enhancing aquaculture productivity, while Jamu and Ayinla [54] and Boyd and Tucker [35] provide insights into how these factors affect the viability of new technologies. Understanding the diffusion process helps identify which innovations are likely to be adopted, the conditions necessary for successful viability, and the overall impact on productivity and sustainability, as emphasized by Hishamunda and Ridler [39] and FAO [36]. Thus, the diffusion of innovations theory is instrumental in assessing and improving the viability of small-scale pond aquaculture in the Lake Victoria region by explaining the viability and implementation of new fish farming practices.

2 Study area

The study was conducted in the districts of Mpigi, Buikwe, and Wakiso in Uganda's Lake Victoria basin (Fig. 2), an area spanning more than 31,000 km^2 and accounting for more than 93% of the country's fish production [55]. Every district has a different climate: Wakiso has average temperatures between 17 and 27 degrees, with an annual rainfall of approximately 1597 mm; Buikwe has average temperatures between 26 and 30 degrees, with an annual rainfall of approximately 1200 mm; and Mpigi has seasonal variations between 24 and 28 degrees, with an annual rainfall of approximately 1000 mm. The high altitude, rich soils, and copious water resources of the basin, which include large

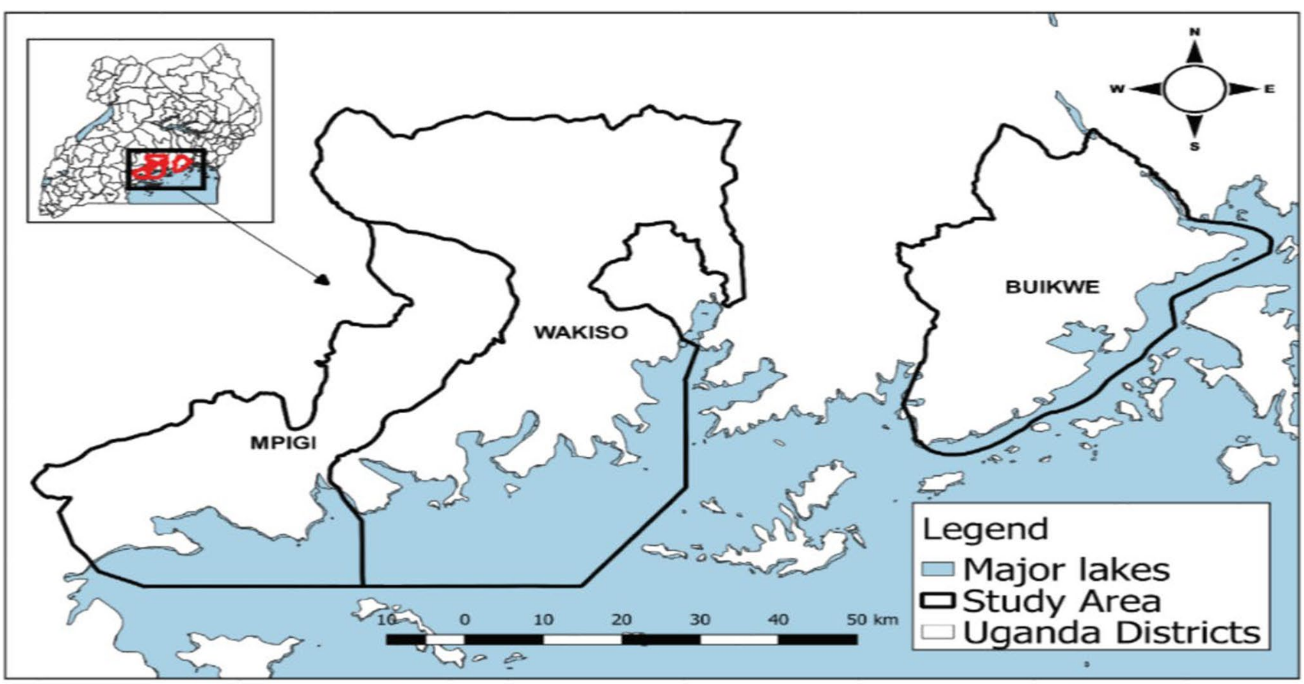

Fig. 2 Map of the study area

rivers such as the Nile and Katonga, support a variety of agricultural and aquacultural pursuits that are advantageous to rural people on an ecological and economic level.

3 Materials and methods

3.1 Household surveys

The study used household surveys and focus group discussions (FGDs) to investigate farmers' perceptions of the viability of small aquaculture and insights into family food security. The use of mixed techniques made it easier to examine both quantitative and qualitative data, allowing for a more thorough evaluation of small-scale pond aquaculture technologies in the rural Lake Victoria Basin.

3.2 Focus group discussion (FGD)

Three focus group discussions (FGDs) were held in October 2023 to help draft a survey questionnaire, one in each of the three target districts: Buikwe, Mpigi, and Wakiso. The focus groups ranged from 10 to 18 respondents, with a total of 26 respondents throughout the three districts. The primary goals of the FGDs were to gain insights into specific small-scale pond aquaculture practices, understand the input supply and value chain for small aquaculture, identify barriers and constraints to small aquaculture viability, and investigate the general perspectives and views of farmers participating in the MAAIF Aquaculture Programme in the Lake Victoria basin.

3.3 Household survey questionnaire (HSQ)

The household survey aimed to gain insights into various aspects of fish farming households, including their characteristics, fish production levels, barriers to adopting small-scale pond aquaculture, and reasons for discontinuing aquaculture practices. To design the survey questionnaire, we synthesized information from diverse sources, such as literature reviews, established survey methodologies, and reports on fish production in the Lake Victoria basin. Additionally, observations made during the Lake Victoria Basin Aquaculture Program informed the initial drafting of the questionnaire. To ensure comprehensive coverage of key aspects related to small-scale pond aquaculture in the Lake Victoria basin, we conducted a pretesting phase of the survey in September 2023. Furthermore, insights obtained from focus group discussions were incorporated into refining the questionnaire.

3.4 Sampling method

The evaluation questionnaire employed the technique of cluster sampling, targeting 457 small-scale pond aquaculture farmers in the Lake Victoria basin across three specific districts. To ensure statistical validity, a minimum sample size of 169 farmers was deemed necessary. The study aimed to reduce standard error by assigning five households to each cluster and proportionally allocating clusters among the three districts while adjusting for variations in cluster numbers. The distribution of sample clusters per district was as follows: 10 in Buikwe, 7 in Wakiso, and 5 in Mpigi. Clusters were chosen through simple random sampling, ensuring equal village representation. Villages were randomly selected based on a numbering system. The survey sample consisted of both current and past program respondents, with households chosen randomly within the selected villages. A reserve sample was also prepared to substitute for households unavailable for interviews from the primary sample.

3.5 Data collection and analysis

In October 2023, a team of four enumerators, selected from aquaculture and fisheries officers in the surveyed districts, underwent training to complete a household survey. The researcher closely monitored the training processes to ensure the accuracy of the collected data. Data entry was performed using Microsoft Excel, and the data were cleaned by importing the datasets into Stata for frequency analysis and cross-tabulation to maintain consistency and accuracy. A total of 169 households participated in the study, all of whom consented to be interviewed. The responses of the participants were utilized for data analysis, which included the use of descriptive statistics such as frequency, mean, and standard deviation. Additionally, insights from focus group discussions complemented the study's findings. To compare the attitudes of respondents we employed the Mann–Whitney U test**,** a non-parametric test, to compare the attitudes of respondents who continued fish farming with those who discontinued who continued fish farming with those who discontinued fish farming.

4 Results and discussion

4.1 Demographic characteristics

Table 1 presents the demographic characteristics of the respondents, including age, sex, education level, marital status, experience in fish farming, land ownership, income levels, and employment status.

The average age was 38.6 years, with the majority between 31 and 50 years, indicating combination of youthful energy and experienced expertise. This aligns with findings from Kumar and Engle [31], who note that a mix of young and more experienced farmers can be advantageous for the viability of new technologies. Experienced farmers, who make up a significant portion of the population in the small-scale pond aquaculture field with more than 8 years of experience, can mentor less experienced farmers, potentially enhancing overall productivity and innovation within the sector [56]. Furthermore, Jamu and Ayinla [14] emphasize the importance of leveraging experienced farmers to spread best practices, which could be crucial in regions with diverse experience levels. There was a significant sex difference, with males comprising 60.4% and females comprising 39.6%. Studies by the FAO [53] on gender dynamics in Ugandan agriculture

Table 1 Demographic characteristics of the respondents

Characteristic	Category	Frequency (n = 169)	Percentage (%)	SD	CI
Age	18–30 years	40	23.7	38.6 ± 11.2	(36.5, 40.7)
	31–40 years	50	29.6		
	41–50 years	43	25.4		
	51–60 years	25	14.8		
	61 years and above	11	6.5		
Sex	Male	102	60.4		
	Female	67	39.6		
Education level	No formal education	20	11.8		
	Primary education	78	46.2		
	Secondary education	45	26.6		
	Tertiary education	26	15.4		
Marital status	Single	29	17.2		
	Married	118	69.8		
	Divorced	15	8.9		
	Widowed	7	4.1		
Experience in fish farming	Less than 1 year	32	18.9	5.7 ± 2.3	(5.2, 6.2)
	1–5 years	48	28.4		
	6–8 years	44	26		
	More than 8 years	45	26.7		
Land ownership	Owned	101	59.8		
	Rented	45	26.6		
	Communal	23	13.6		
Income levels	Small income	94	55.6	2.1 ± 1.2	(1.9, 2.3)
	Medium income	61	36.1		
	Large income	14	8.3		
Employment status	Full-time fish farming	72	42.6		
	Part-time fish farming	97	57.4		

suggest that women often face barriers to participation and access to resources. The FAO [12, 57] notes that addressing gender disparities is essential for improving agricultural outcomes. Initiatives such as targeted training programs for women and efforts to enhance their access to resources could help bridge this gap, as supported by Brummett et al. [30], who emphasize that inclusive approaches improve the overall effectiveness of small-scale pond aquaculture interventions. With most small-scale fish farmers having a primary education (46.2%) and a significant portion holding secondary (26.6%) or tertiary qualifications (15.4%), the educational background of the farmers is relatively varied. According to Boyd & Tucker [35], higher education levels are often associated with increased acceptance of innovative small-scale aquaculture practices. However, in Uganda, Kumar and Engle [31] noted that while education is crucial, practical training and extension services are equally important for translating education into improved aquaculture practices. Thus, enhancing both educational and practical training opportunities leads to better outcomes in the aquaculture sector. The high proportion of married individuals (69.8%) and the fact that many farmers engage in aquaculture as a secondary activity (57.4%) suggest that fish farming is often a supplementary income source. This finding is consistent with Hishamunda and Ridler [41], who highlight that many small-scale fish farmers in developing countries use aquaculture as an additional livelihood strategy. The challenge is to ensure that fish farming is not only supplementary but also a viable primary income source. The FAO [36] advocates for policies that support full-time engagement and investment in aquaculture to enhance profitability and sustainability. The majority of fish farmers own their land (59.8%), which is a positive indicator of investment in small-scale pond aquaculture. However, the income distribution shows that most farmers earn less income (55.6%), with only a small fraction achieving higher earnings (8.3%). Jamu and Ayinla [14] and Boyd and Tucker [35] emphasize the need for improved access to markets, financial services, and production inputs to increase profitability. Enhancing access to credit and investment in aquaculture technologies help increase income levels and the overall viability of small-scale pond aquaculture.

4.2 Alternative sources of income for small-scale pond aquaculture farmers in the Lake Victoria Basin

For small-scale pond aquaculture fish farmers in the Lake Victoria basin, alternative sources of income play a crucial role in supplementing their earnings. Table 2 provides a detailed breakdown of these income sources, including their frequency (number of farmers engaged), percentage of total farmers, and the proportion of income contributed by each source (Table 2).

The results indicate that crop cultivation is the predominant alternative source of income for 32% of small-scale fish farmers, contributing 30% to their total income, while livestock sales engage 19.53% of farmers and account for 25% of their income. Merchandise businesses and wages also play significant roles, each contributing 15% to overall income and involving 18.32% and 12.43%, respectively, of farmers. Formal monthly salaries and remittances, although less common (engaging 9.47% and 8.28%, respectively), still make substantial contributions, with formal salaries accounting for 10% of total income. This pattern is consistent with the study by Ellis [58], which emphasized the importance of income diversification among rural households as a strategy to mitigate risks and enhance economic stability. The FAO [53] highlights the significance of combining agricultural and nonagricultural activities for ensuring household resilience and income stability. Our results align with the broader understanding of the FAO [11] that, while fish farming remains central to fish farmers, the integration of complementary income sources is crucial for sustaining rural economic viability. These income diversification strategies are essential for fostering rural economic sustainability and resilience against market fluctuations and environmental uncertainties.

Table 2 Alternative sources of income for small-scale pond aquaculture fish farmers

Income-alternative	Frequency (number of farmers)	Percentage (%)	Proportion of income (%)
Sale of livestock (goats, cows, pigs)	33	19.53	25
Crop cultivation	54	32	30
Formal monthly salary	16	9.47	10
Remittances	14	8.28	5
Wages	21	12.43	15
Merchandise business	31	18.32	15

Table 3 Small-scale pond aquaculture production and farmer engagement across districts

District	Active fish farmers (%)	Completed cycles (mean)	Fish produced (mean kg)	Pond size (mean m^2)	Continued fish farming	Discontinued fish farming	Z–	(r)
Buikwe (n = 65)	86.15%	1.78*	470.0*	271*				
Mpigi (n = 49)	77.50%	1.45	274.3	127.01				
Wakiso (n = 55)	87.27%	1.51	434.1*	162.1*				
Total (n = 169)	84.02%	1.93	426.3	243	118	51	2.5	0.2

*Statistically significant values.

Table 4 Variations in small-scale pond fish farming metrics

Variables	SS	Df	MS	Tukey's HSD	P-value
Completed cycles	1.12	2	0.56	Buikwe > Mpigi, Wakiso > Mpigi, Buikwe > Wakiso	0.0004
Fish produced	154,440	2	77,220	Buikwe > Mpigi, Wakiso > Mpigi, Buikwe > Wakiso	0.0009
Pond size	358,634	2	179,317	Buikwe > Mpigi, Wakiso > Mpigi, Buikwe > Wakiso	0.0002

4.3 Small-scale pond aquaculture production and farmer engagement across districts

Results (Table 3), indicate that 84.02% of the farmers across Buikwe, Mpigi, and Wakiso districts were actively engaged in aquaculture, with Buikwe (86.15%) and Wakiso (87.27%) showing higher participation than Mpigi (77.50%). The mean number of completed production cycles across all districts was 1.93, with Buikwe significantly leading at 1.78 cycles ($P < 0.05$). Fish production averaged 426.3 kg, with Buikwe (470.0 kg) and Wakiso (434.1 kg) outperforming Mpigi (274.3 kg). Pond sizes averaged 243 m^2, with Buikwe having the largest ponds (271 m^2) and Mpigi the smallest (127.01 m^2). Of the 169 total respondents, 118 continued fish farming, while 51 discontinued. The Mann–Whitney U test revealed a Z-score of 2.5, indicating a statistically significant difference in attitudes between those who continued and discontinued fish farming, though the effect size (r) was modest at 0.2, suggesting that while attitudes differ, other factors likely influence the decision to continue or discontinue farming.

Fish production averages 426.3 kg across all districts, with Buikwe (470.0 kg) and Wakiso (434.1 kg) significantly outperforming Mpigi (274.3 kg). Pond sizes vary, averaging 243.4 m^2, with Buikwe having the largest (271.0 m^2) and Mpigi the smallest (127.01 m^2). The higher productivity in Buikwe and Wakiso correlates with larger pond sizes and greater farmer engagement, underscoring the importance of these factors in enhancing aquaculture productivity. These findings align with studies on the critical role of pond size and management practices in aquaculture productivity. Studies have shown that larger pond sizes often lead to higher fish yields due to better resource management and optimized growth conditions [59]. Moreover, active farmer participation is crucial for successful aquaculture, as it typically reflects better training, access to resources, and the viability of best small-scale pond aquaculture practices [42]. The significantly greater production in Buikwe and Wakiso suggests that these districts benefited from superior infrastructure and support systems, which could serve as models for Mpigi. Improving pond sizes and increasing farmer engagement could enhance productivity, as demonstrated by the higher-performing districts. Our results emphasize the need for targeted interventions and resource allocation to support small-scale pond aquaculture, particularly in underperforming districts.

4.4 Variation in small-scale pond fish farming metrics

Table 4 presents the results of the ANOVA test assessing differences in completed cycles, fish production, and pond size among the fish farming districts.

The statistical analyses revealed significant variations in small-scale fish farming metrics across the districts of Buikwe, Mpigi, and Wakiso (Table 4). A significant difference was found in the number of completed production cycles between the districts ($P = 0.0004$), with Tukey's HSD indicating that Buikwe significantly outperformed both

Mpigi and Wakiso, while Wakiso also showed higher performance compared to Mpigi. Similarly, there was a significant difference in the average fish production (P = 0.0009), with Buikwe producing significantly more fish than both Mpigi and Wakiso, and Wakiso outperforming Mpigi. These differences likely reflect variations in farming practices, pond management, and resources. Additionally, significant differences in pond size were found (P = 0.0002), with Buikwe having significantly larger ponds compared to both Mpigi and Wakiso, and Wakiso having larger ponds than Mpigi. Larger ponds likely provide better conditions for higher yields, explaining the higher productivity observed in Buikwe and Wakiso.

The results presented in Table 4 show significant differences in completed production cycles, fish production, and pond sizes across the districts of Buikwe, Mpigi, and Wakiso. For completed cycles, the P-value of 0.0004 indicates that Buikwe and Wakiso significantly outperformed Mpigi, with Buikwe showing the highest completion rate, followed by Wakiso. Similarly, fish production also differed significantly across the districts, with a P-value of 0.0009, revealing that Buikwe produced the most fish, followed by Wakiso, and Mpigi producing the least. Pond sizes showed significant variability across the districts, with a P-value of 0.0002, indicating that Buikwe had significantly larger ponds than both Mpigi and Wakiso, and Wakiso had larger ponds than Mpigi. Larger pond sizes are likely contributing to better conditions for fish growth and higher yields, particularly in Buikwe and Wakiso. These findings align with previous study emphasizing the importance of pond size, farmer engagement, and regional support systems in enhancing aquaculture productivity [42, 59]. Buikwe and Wakiso, which demonstrated superior infrastructure and management practices, have better access to resources and support for aquaculture, as reflected in their higher productivity metrics. In contrast, Mpigi's lower performance may be attributed to smaller pond sizes and less frequent production cycles, suggesting a need for improved resources and infrastructure. Policy interventions should focus on improving pond sizes, providing training, and optimizing infrastructure in underperforming districts like Mpigi. The findings underscore the importance of addressing regional disparities in resources and management to promote sustainable and productive small-scale pond aquaculture throughout the region. Targeted efforts to improve infrastructure, support systems, and access to resources in lower-performing districts would enhance productivity and overall sustainability. These results emphasize the need for continued investment in farmer education, infrastructure development, and efficient management practices to achieve greater aquaculture productivity across the region.

4.5 Small-scale pond aquaculture fish production by species

Table 5 shows significant differences in mean small-scale pond aquaculture fish production (kg/m^2) by species and district. Wakiso consistently outperforms other districts in the production of Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*), with mean productions of 1.70 kg/m^2 (SD 1.71) and 2.05 kg/m^2 (SD 1.15), respectively.

This finding suggested that Wakiso's management practices or environmental conditions are more conducive to increasing yields of these species. Buikwe excels in Mudfish (*Protopterus spp*.) production, achieving a mean of 1.94 kg/m^2 (SD 2.69), which may indicate specialized practices or optimal local conditions. However, Nile perch (*Lates niloticus*) production is more variable, with a higher total average production of 2.41 kg/m^2 (SD 3.72) despite lower values in some districts, reflecting inconsistencies in production practices or environmental factors. Our findings are consistent with recent studies on small-scale pond aquaculture [19, 43, 60]. Dey et al. [61] emphasized that variations in water quality, feed management, and farm management practices significantly influence fish production, which aligns with the observed differences across districts. Chiu et al. [39] support the idea that optimized local practices can enhance productivity, explaining why districts such as Wakiso show higher yields. Additionally, Mwanja et al. [52] highlighted the importance of tailoring aquaculture practices to local conditions, which resonates with the variability noted in Nile Perch production and the successes seen in Buikwe and Wakiso. These insights suggest that adopting successful practices from high-performing districts and addressing variability, particularly for species with inconsistent production, such as

Table 5 Mean small-scale pond aquaculture fish production by species and district (kg/m^2)

Fish species	Scientific name	Buikwe (SD)	Mpigi (SD)	Wakiso (SD)	Total (SD)
Nile tilapia	*Oreochromis niloticus*	1.03 (1.10)	1.20 (0.64)	1.70 (1.71)	1.57 (1.51)
African catfish	*Clarias gariepinus*	1.21 (0.67)	1.56 (1.41)	2.05 (1.15)	1.66 (1.11)
Nile perch	*Lates niloticus*	0.21 (1.26)	1.32 (1.52)	1.25 (5.42)	2.41 (3.72)
Mudfish	*Protopterus spp*	1.94 (2.69)	0.61 (0.00)	1.19 (1.48)	1.57 (2.16)

SD standard deviation

Nile Perch, could improve overall productivity. Therefore, policymakers should focus on disseminating best practices, enhancing resource allocation, and improving infrastructure to support small-scale pond aquaculture across all districts.

4.6 Drivers of participation in small-scale pond aquaculture

The results (Table 6) indicate that the primary drivers of small-scale pond aquaculture participation were the scarcity of wild fish, the potential for higher earnings from aquaculture activities, the appeal of working from home, and improved food availability within the household. The scarcity of wild fish was identified as the most significant factor (P = 0.045), with 87% of respondents reporting that this scarcity influenced their decision to engage in aquaculture. The potential for higher earnings from aquaculture was also a significant driver (P = 0.018), with 37% of respondents indicating that financial gain from aquaculture activities motivated their participation. Conversely, the appeal of working from home (P = 0.406) and improved food availability within the household (P = 0.183) were not statistically significant drivers, with only 29% and 15% of respondents, respectively, reporting these as factors influencing their decision to farm fish.

The potential for higher earnings ranks second, with a value of 1.3421 and a P-value of 0.018, reflecting its considerable impact, though it is slightly less than that of wild fish scarcity. Working from home followed, with a value of − 0.5612 and a P-value of 0.406, indicating moderate significance. Improved food availability had the lowest value (0.4567) and a P-value of 0.183, suggesting that it was the least significant driver among the factors analyzed. The prominence of the scarcity of wild fish as the primary driver aligns with broader studies, emphasizing that declining wild fish stocks significantly drive the viability of aquaculture as an alternative source of fish, consistent with Dey et al. [61] and Chiu et al. [39]. The substantial potential for higher earnings supports existing research highlighting economic incentives as major motivators for aquaculture involvement [52].

The moderate significance of working from home reflects a growing trend toward flexible, home-based aquaculture enterprises [59]. Last, the lower significance of improved food availability suggested that while it is a recognized benefit, it is overshadowed by more immediate economic and supply-related factors, aligning with Ahmed and Lorica's observations that practical concerns often outweigh food security benefits in small-scale pond aquaculture [42].

Focus group discussions (FGDs) further illuminated these findings. In Buikwe, 21 participants noted, "*I am engaged in managing two ponds independently, without external assistance. Furthermore, I now possess two ponds under my own supervision*." In Mpigi, 18 participants shared similar sentiments, "*Aquaculture venture has provided a reliable income, which is crucial given the low availability of wild fish*." In Wakiso, 15 participants emphasized the appeal of home-based operations, with participants remarking, "*Being able to manage my aquaculture business from home has been a major advantage, especially during the COVID-19 epidemic*." These fish farmer responses highlight the real implications of the statistical findings, demonstrating how practical experiences and local conditions influence the perceived drivers of small-scale pond aquaculture participation.

4.7 Barriers to the participation and choice of small-scale pond aquaculture

The results in Table 7 indicate the factors influencing participation in and decision-making about small-scale pond aquaculture. Market availability and access, with a coefficient (β) of 0.6 and a highly significant p value of 0.0001, have the most substantial positive impact on participation, underscoring the importance of reliable market access for farmers. These findings align with those of a study by Kawarazuka and Béné [24], who emphasized the role of market integration in enhancing fish farmers' livelihoods. Similarly, low knowledge and skills (β = 0.5, p = 0.005) significantly hinder participation, highlighting the need for training programs to enhance technical know-how. Studies by Jamu and Ayinla [14] support this, noting that capacity building through education and training is essential for effective aquaculture development.

Table 6 Drivers of small-scale pond aquaculture choices and participation

Drivers to participation	Respondents (%)	β	SE	z-Value	P-value	VIF	R^2
Scarcity of wild fish	87	0.9123	0.456	2.003	0.045	2.04	0.88
Potential for higher earnings from aquaculture	37	1.3421	0.567	2.366	0.018	1.57	0.88
Appeal of working from home	29	− 0.5612	0.675	− 0.831	0.406	1.1	0.88
Improved food availability within household	15	0.4567	0.342	1.334	0.183	1.25	0.88

Table 7 Barriers to participation in and choice of small-scale pond aquaculture

Barrier	Coefficient (β)	Standard error	t-Statistic	p-Value	VIF	R^2
Market availability and access	0.6	0.1	6	0.0001**	1.22	0.85
Low knowledge and skills	0.5	0.15	3.33	0.005*	1.15	0.8
Limited access to water source	0.55	0.12	4.58	0.001**	1.18	0.82
Fingerling prices	0.3	0.2	1.5	0.15 ns	1.1	0.75
Fish feed quality	0.4	0.18	2.22	0.045*	1.25	0.79
Unsecure land tenure	0.2	0.25	0.8	0.425 ns	1.3	0.72
Market price of fish	0.1	0.3	0.33	0.74 ns	1.1	0.7
Fish feed prices	0.05	0.35	0.14	0.89 ns	1.05	0.65
Small fish farming operations	0.08	0.28	0.29	0.77 ns	1.2	0.68
Limited labor	0.07	0.3	0.23	0.82 ns	1.13	0.6
Unprofitable venture	0.12	0.32	0.38	0.71 ns	1.1	0.63

* *ns* not significant

Significant at the 0.05 level (0.01 ≤ p < 0.05), **highly significant at the 0.01 level (p < 0.01)

Limited access to water sources (β = 0.55, p = 0.001) is another critical barrier, emphasizing the necessity of a reliable water supply for sustainable aquaculture. Our findings agree with a study by the WorldFish Center [62], which identified water access as a fundamental requirement for successful aquaculture practices. Fish feed quality (β = 0.4, p = 0.045) also significantly impacts participation, indicating that improving feed quality boosts productivity. Ngugi, Bowman, and Omolo [41] highlighted that high-quality feed is vital for the growth and health of fish and directly affects the profitability of aquaculture operations. In contrast, fingerling prices, unsecure land tenure, the market price of fish, fish feed prices, the scale of farming operations, limited labor, and perceptions of unprofitability had no statistically significant impact on participation. Farmers have a stable market across the central region, and they find that these issues do not affect aquaculture production. These findings align with a recent study by the FAO [12] in Uganda, where market access, technical training, and resource availability are consistently highlighted as key determinants of successful small-scale pond aquaculture development, whereas prices and land tenure security are often less immediate concerns than market access and technical capacity in determining participation in aquaculture ventures. Our findings from this study have crucial implications for the aquaculture sector in the Lake Victoria Basin, Uganda. The strong impact of market availability on participation underscores the need for better market infrastructure, transportation networks, and market information systems. The significant barrier posed by low knowledge and skills highlights the need for comprehensive training programs in fish farming and business management. Limited access to water sources necessitates improved water resource management, such as irrigation systems and rainwater harvesting. Improving fish feed quality is essential and requires enhanced local production and quality standards. We suggest a holistic approach to policy formulation, reducing barriers, and providing investment incentives to support small-scale pond aquaculture and enhance food security and livelihoods.

4.8 Diverse opinions on small-scale pond aquaculture practices among respondents

Respondents had a positive view of small-scale pond aquaculture (Table 8), as indicated by a statistically significant negative z value of − 4.324 (p = 0.0001), reflecting strong endorsement of the practice. However, compared with lake fish, they perceive farmed fish as inferior in quality, as indicated by a positive z value of 2.371 (p = 0.0001). While the availability of fish feed in the district is perceived as moderate (z = 1.503, p = 0.346) and challenges in affording food are occasionally noted (z = 1.251, p = 0.1678), these issues do not reach statistical significance, suggesting variability in economic stability. Small-scale pond aquaculture is considered highly risky (z = 3.140, p = 0.0034); however, respondents are inclined to recommend it to others (z = − 2.630, p = 0.0231), indicating the recognition of potential benefits despite the risks. Limited access to high-quality fingerlings (z = − 1.861, p = 0.0002) and the perceived conservation impact in the Lake Victoria Basin (z = − 2.134, p = 0.0001) highlight areas needing improvement and the ecological benefits seen by respondents. Finally, the view that small-scale pond aquaculture is economically viable and profitable (z = − 2.834, p = 0.0034) underscores its perceived economic potential.

Our findings suggest that while there are positive perceptions and recognized benefits of small-scale pond aquaculture, significant concerns remain regarding the quality of farmed fish, associated risks, and resource accessibility. These concerns align with the literature, which highlights that small-scale pond aquaculture, despite its potential, often faces

Table 8 Diverse opinions on small-scale pond aquaculture practices among respondents

Opinion	z value	p value
My perception of small-scale pond aquaculture is positive	– 4.324	0.0001*
I believe farmed fish are inferior in quality compared to wild lake fish	2.371	0.0001*
Availability of fish feed in my district is moderate	1.503	0.346**
Occasionally, affording food for myself or my family is challenging	1.251	0.1678**
Small-scale pond aquaculture is perceived as highly risky	3.14	0.0034*
I am inclined to recommend small-scale pond aquaculture to friends and family	– 2.63	0.0231*
The accessibility of high-quality fingerlings in my district is limited	– 1.861	0.0002*
Small-scale pond aquaculture aid in conserving natural resources in the Lake Victoria basin	– 2.134	0.0001*
It is seen as economically feasible and profitable to engage in small-scale pond aquaculture	– 2.834	0.0034*

*Opinion about small-scale pond aquaculture is statistically significant ($p \leq 0.05$). **Opinion not statistically significant ($p > 0.05$)

challenges related to fish quality and resource constraints. This finding is in line with the findings of other studies. For instance, Brummett et al. [30] noted that perceptions of lower quality meat in farmed fish compared to wild catches can affect consumer acceptance and marketability. The perception of high risks associated with aquaculture is supported by the work of Little et al. [63, 64], who emphasize that uncertainties in production and market conditions can deter investment and expansion in the sector. However, the economic viability and conservation benefits of small-scale pond aquaculture are well documented. According to the WorldFish Center [65], small-scale pond aquaculture can significantly enhance local livelihoods by providing income and food security. Furthermore, the potential for small-scale pond aquaculture to contribute to environmental conservation is supported by the study by Dey et al. [61], who highlighted how well-managed small aquaculture can aid in preserving aquatic ecosystems and reducing pressure on wild fish stocks. The findings from our study highlight the critical role of small-scale pond aquaculture as a key contributor to rural livelihoods and economic stability, particularly in Buikwe and Wakiso, where production efficiencies are higher. These districts can serve as models for scaling up fish farming practices across Uganda. Conversely, the findings also underscore the importance of income diversification strategies, as emphasized by the FAO [11], to ensure long-term economic resilience for farming households. This is especially crucial in the underperforming district of Mpigi, where targeted interventions, such as improving access to inputs, training, and infrastructure, can help close the productivity gap and ensure that small-scale aquaculture contributes more effectively to household income stability.

5 Limitations of the study

While our study provides valuable insights into the viability of small-scale pond aquaculture in the Lake Victoria Basin, several limitations must be acknowledged. First, the scope of the research was limited to three districts: Buikwe, Mpigi, and Wakiso. This geographical restriction may not fully capture the diversity of aquaculture practices and challenges across the entire basin. Second, the study relied on self-reported data from fish farmers, which may introduce biases or inaccuracies due to misreporting or recall errors. Third, the cross-sectional nature of the study limits the ability to infer causality between observed factors and aquaculture productivity. Including environmental impacts would have required additional resources and was not feasible within the original scope of our study. Lastly, resource constraints limit the depth of analysis of certain aspects, such as the environmental impact of aquaculture practices and the detailed economic analysis of different farming models.

6 Conclusion and recommendations

The findings of small-scale pond aquaculture viability in the Lake Victoria Basin reveal both opportunities and challenges that are critical for the sector's development. The demographic profile of fish farmers, encompassing a blend of young and experienced individuals, underscores the sector's potential for innovation combined with expertise. However, gender disparities and income limitations point to the need for targeted training, enhanced financial access, and policies that support full-time farmer engagement to boost sustainability and productivity in small-scale pond aquaculture. The analysis of production highlights significant disparities. Buikwe and Wakiso exhibit superior productivity and management practices, attributed to larger pond sizes and more active farmer participation. In contrast, Mpigi Lags behind, suggesting that targeted interventions related to pond size and management could significantly enhance productivity. The superior yields of Nile tilapia and African catfish in Wakiso and the success of Buikwe with Mudfish illustrate the importance of tailored practices and optimized environmental conditions. Barriers to participation, including market access, low knowledge and skills, and limited water sources, are pivotal in shaping farmer engagement. Market access and technical expertise are crucial for fostering participation, but water scarcity remains a significant hurdle. Addressing these barriers through improved market infrastructure, comprehensive training, and better water resource management is essential for enhancing the sector's effectiveness. Although issues such as fish feed quality and resource constraints are prevalent, they can be mitigated through targeted interventions. The study also revealed the importance of alternative income sources, with crop cultivation playing a significant role in diversifying farmers' revenue streams and contributing to economic resilience. Understanding these livelihood strategies is vital for developing holistic development programs that integrate aquaculture with other income-generating activities. Our findings emphasize the need for a multifaceted approach to unlock the potential of small-scale pond aquaculture in the Lake Victoria Basin. By addressing barriers, leveraging successful practices from higher-performing districts, and supporting economically disadvantaged farmers, small-scale fish farmers can enhance livelihoods, conserve natural resources, and promote small-scale pond aquaculture in the Lake Victoria Basin, Uganda.

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Author contributions SB conceived the study design, conducted surveys and focus group discussions, oversaw data collection, performed data analysis and interpretation, and drafted the manuscript. ML and SR provided essential supervision, guidance, and revisions to the manuscript. All authors reviewed the manuscript.

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Data availability The data sets analysed during this current study are available from corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The study protocol was approved by the Department of Aquaculture and Fisheries at Lilongwe University of Agriculture and Natural Resources. Informed consent was obtained from all participants prior to focus group discussions and data collection, with strict assurances of data confidentiality. Clinical Trial: Not applicable, and study was conducted following approval from Lilongwe University of Natural Resource.

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