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Climate-Smart Aquaculture Adoption in Rural Areas around Lake Victoria, Tanzania: Gender, Socioeconomic, and Institutional Influences

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Abstract

Climate-Smart Aquaculture (CSAq) is increasingly recognized as a sustainable adaptation strategy to enhance aquaculture productivity, resource efficiency, and climate resilience. However, socioeconomic and institutional constraints continue to shape CSAq adoption patterns, particularly among smallholder farmers. This study examines the determinants of CSAq adoption in Tanzania's Lake Zone, using a Multinomial Logit (MNL) model to analyze survey data from 384 fish farmers. The model assesses the likelihood of adopting Integrated Aquaculture-Agriculture (IAA), Polyculture, or Monoculture (baseline category) based on household characteristics, financial access, extension services, and education levels. The findings reveal that household size ($p < 0.05$), education level ($p < 0.05$), financial grants ($p < 0.01$), and extension services ($p < 0.01$) significantly influenced CSAq adoption. Larger households and better-educated farmers were more likely to adopt IAA, while financial support and extension services were associated with higher Monoculture adoption rather than CSAq. This suggests that current institutional support structures may be reinforcing conventional single-species fish farming rather than promoting climate-resilient aquaculture models. Gender was not statistically significant, indicating that CSAq adoption disparities are more closely linked to financial and institutional constraints rather than direct gender-based preferences. These findings highlight the urgent need to realign financial incentives, extension programs, and training initiatives to promote climate-smart aquaculture adoption. Policies should prioritize CSAq financing models, and integrate climate-smart training into extension services. Strengthening institutional support mechanisms and enhancing smallholder farmers' access to CSAq knowledge and resources will be critical for achieving climate resilience, food security, and rural economic development in Tanzania's aquaculture sector.

Keywords: Climate-Smart Aquaculture (CSAq), Institutional Constraints, Multinomial Logit Regression, Rural Development, Tanzania, Lake Victoria.

1. Introduction

Climate change has emerged as a major threat to global food security and rural livelihoods, particularly in developing regions highly dependent on natural resources (FAO, 2022; IPCC, 2023). The fisheries and aquaculture sectors, which support the livelihoods of over 58.5 million people worldwide, are particularly vulnerable to climate variability, extreme weather events, and environmental degradation (FAO, 2023). In sub-Saharan Africa, where small-scale aquaculture plays a vital role in nutrition, income generation, and employment, the impacts of climate change threaten the sustainability of fish farming systems and the resilience of rural communities (Obiero et al., 2019). This has led to the emergence of Climate-Smart Aquaculture (CSAq) as an innovative strategy to enhance productivity, promote resource efficiency, and improve adaptation to climate-related stressors (Ahmed et al., 2021).

Tanzania's aquaculture sector, particularly in the Lake Zone regions surrounding Lake Victoria, is increasingly recognized for its potential to boost rural development, economic diversification, and food security (Njaya et al., 2021). However, despite the sector's growth prospects, the adoption of CSAq remains limited, particularly among smallholder farmers, women, and youth (Maulu et al., 2023). The transition from traditional Monoculture to climate-resilient systems such as Integrated Aquaculture-Agriculture (IAA) and Polyculture requires institutional support, financial access, capacity building, and gender-inclusive policies. Limited research exists on the socioeconomic and institutional determinants of CSAq adoption, creating an urgent need for empirical studies that identify the barriers and opportunities for scaling climate-smart aquaculture in rural Tanzania.

The adoption of CSAq aligns with several United Nations Sustainable Development Goals (SDGs), particularly those related to food security, poverty reduction, environmental sustainability, and gender equality. CSAq contributes directly to SDG 2 (Zero Hunger) by improving aquaculture productivity and fish availability, enhancing the nutritional status of rural communities (FAO, 2023a). Additionally, by providing income opportunities for smallholder farmers, women, and youth, CSAq supports SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) (Adam et al., 2022). The integration of aquaculture with sustainable land and water management practices contributes to SDG 13 (Climate Action) and SDG 15 (Life on Land) by promoting climate adaptation and biodiversity conservation (World Bank, 2022).
Despite its potential, the implementation of CSAq remains unevenly distributed across rural areas due to socioeconomic constraints, limited institutional support, and gender disparities. Strengthening CSAq adoption requires a multi-sectoral approach that addresses financial inclusion, knowledge dissemination, and policy interventions, ensuring that vulnerable rural populations benefit from climate-resilient aquaculture strategies (Lind et al., 2022).

Gender disparities in aquaculture production and rural development remain a major constraint to achieving inclusive growth in the fisheries sector. Women, despite playing a crucial role in post-harvest processing, marketing, and small-scale fish farming, continue to face barriers to credit access, land ownership, and technical training, limiting their ability to transition into commercial and climate-smart aquaculture systems (Njaya et al., 2021). Studies show that men are more likely to engage in capital-intensive and technologically advanced aquaculture systems, while women are often confined to traditional, low-yield fish farming practices due to limited institutional support and socio-cultural restrictions (Alonso-Población & Siar, 2018).
Previous research has emphasized the need for gender-sensitive policies in aquaculture that promote women's access to productive resources, extension services, and financial inclusion (Maulu et al., 2023). However, existing studies in Tanzania's Lake Zone have largely overlooked the intersection between gender, CSAq adoption, and rural planning policies. Addressing these knowledge gaps is essential to ensure that CSAq becomes an inclusive strategy for poverty alleviation and climate adaptation in rural communities.

Despite the growing emphasis on CSAq as a climate adaptation strategy, there remains a lack of empirical evidence on the factors influencing its adoption in rural Tanzania. Most previous studies have focused on technical aspects of aquaculture, such as fish productivity and environmental sustainability, with limited attention to the socioeconomic and institutional determinants of CSAq adoption (Ahmed et al., 2021; FAO, 2023b). Furthermore, research on gender dynamics in CSAq adoption remains scarce, particularly in the context of rural development policies and planning frameworks (Njaya et al., 2021).
This study fills these gaps by providing a comprehensive analysis of the socioeconomic, institutional, and gender-related factors shaping CSAq adoption in Tanzania's Lake Zone. By employing a multinomial logit approach, this study offers novel insights into how gender, education, financial access, and policy interventions influence the likelihood of adopting IAA, Polyculture, or Monoculture. Additionally, this research contributes to the broader discourse on climate-resilient food systems, linking CSAq adoption to rural development and the achievement of SDGs.

The main objective of this study is to analyze the role of gender in CSAq adoption and to identify the socioeconomic barriers and facilitators influencing fish farmers' ability to transition to climate-smart aquaculture. Specifically, the study examines the likelihood of men and women adopting different CSAq practices, including Integrated Aquaculture-Agriculture (IAA), Polyculture, and Monoculture, in Tanzania's Lake Zone. It further assesses the impact of key socioeconomic factors such as education, household size, financial support, and access to extension services on CSAq adoption decisions. Additionally, the study aims to develop policy recommendations to enhance gender inclusivity in aquaculture and support the wider adoption of CSAq practices, particularly in climate-vulnerable rural regions (Mbasa et al., 2024).
The remainder of this paper is structured as follows: Section 2 presents the theoretical and conceptual framework, discussing the

Sustainable Livelihoods Framework (SLF) as the guiding theory for understanding CSAq adoption. Section 3 presents the results and discussion, integrating descriptive statistics, institutional factors, and multinomial logit regression findings. Section 4 provides the conclusion and policy recommendations, offering practical strategies to promote gender-inclusive CSAq adoption in rural Tanzania.

2. Theoretical review

The adoption of Climate-Smart Aquaculture (CSAq) is shaped by a combination of socioeconomic, institutional, and environmental factors that influence farmers' decision-making processes. To analyze these dynamics, this study is grounded in the Sustainable Livelihoods Framework (SLF), which provides a comprehensive lens for understanding how livelihood assets, gender roles, and institutional support interact to influence CSAq adoption. The SLF, widely used in rural development studies, examines how individuals and households access, utilize, and transform resources to build resilience against environmental and economic shocks (Scoones, 1998; DFID, 2020). The framework conceptualizes livelihoods around five key assets: human capital (knowledge, skills, education), financial capital (income, access to credit), social capital (networks, affiliations), natural capital (land and water resources), and physical capital (infrastructure, technologies) (Carney, 1998; Ellis, 2000). In the context of CSAq adoption, these assets determine farmers' capacity to transition from conventional Monoculture to climate-resilient models such as Integrated Aquaculture-Agriculture (IAA) and Polyculture. For instance, human capital (education, training) enhances technical knowledge on CSAq innovations, while financial capital (credit access) influences investment in aquaculture technologies (Chambers & Conway, 1992; Adam et al., 2022).

A key strength of the SLF is its emphasis on the role of institutions and policies in shaping livelihood outcomes. Farmers' access to extension services, training programs, and financial support mechanisms is largely mediated by institutional structures, which can either facilitate or constrain CSAq adoption (Scoones, 1998). This is particularly relevant in Tanzania's Lake Zone, where institutional barriers such as limited access to agricultural credit and inadequate technical support remain significant challenges to aquaculture development (Amare & Simane, 2017). The SLF also integrates gender as a critical determinant of livelihood strategies, recognizing that men and women have differential access to livelihood assets and decision-making power (Kruijssen et al., 2018). In the context of CSAq, women face systemic barriers in accessing financial capital, land ownership, and technical knowledge, limiting their ability to transition to climate-smart aquaculture systems (FAO, 2022). Applying the SLF, this study provides a gender-sensitive analysis of how livelihood constraints influence CSAq adoption, emphasizing the need for inclusive policies that promote equitable access to aquaculture resources.

While the SLF provides a strong foundation for analyzing CSAq adoption, it is complemented in this study by insights from innovation diffusion theory (Rogers, 2003) to explain how CSAq practices spread among farming communities. The diffusion of innovation perspective suggests that the adoption of new technologies such as climate-smart fish farming techniques depends on awareness, perceived benefits, access to information, and the role of early adopters in influencing others (Feder & Umali, 1993). In Tanzania's Lake Zone, where aquaculture extension services remain limited, understanding the mechanisms of knowledge transfer and adoption patterns is crucial for scaling CSAq innovations (Ahmed et al., 2021). These theoretical perspectives collectively inform the empirical analysis of CSAq adoption, guiding the development of policy recommendations to enhance gender-inclusive, climate-resilient aquaculture in Tanzania's rural economy. The figure 1 show the relationship of the variables.

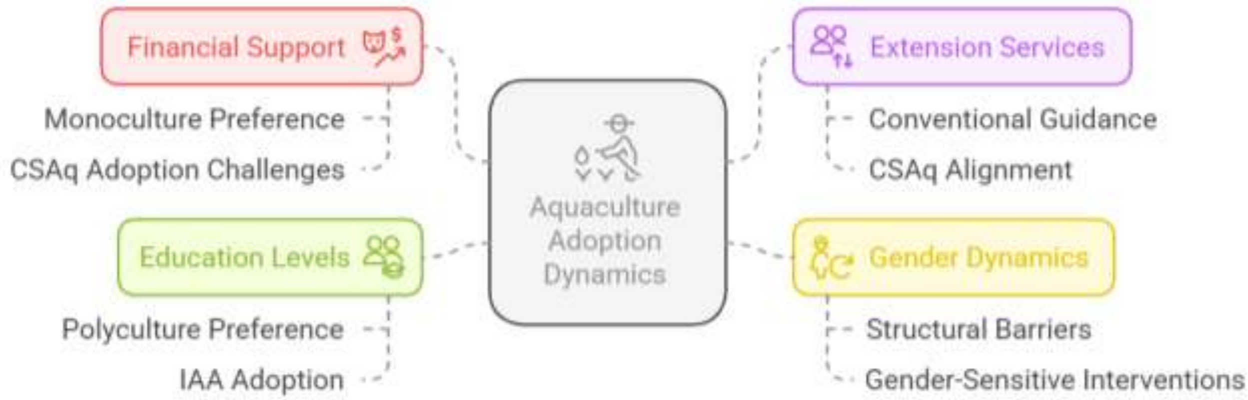


Figure 8: Conceptualized Relationship Between CSAq Adoption Dynamics and Influencing Factors

3. Materials and methods

3.1. Study area

This study was conducted in the two regions around Lake Victoria of Tanzania, namely Mwanza and Mara. The area covered by these regions is a critical hub for Tanzania's fisheries and aquaculture sector, contributing significantly to national fish production, rural livelihoods, and food security (URT, 2022; Jettah et al., 2024). The region's proximity to Lake Victoria the largest freshwater lake in Africa provides ideal conditions for aquaculture, making it a strategic location for promoting Climate-Smart Aquaculture (CSAq) adoption.

The climate of the Lake Zone is characterized by a bimodal rainfall pattern, with long rains from March to May and short rains from October to December, and an average annual temperature ranging between 20°C and 30°C (TMA 2023; Mdoe et al., 2025a). These climatic conditions influence the availability of water resources, fish breeding cycles, and overall aquaculture productivity, making climate variability a key factor in aquaculture sustainability (Mdoe et al., 2025b). In recent years, the region has experienced increased climate-induced stressors, including erratic rainfall, rising temperatures, and declining water quality, necessitating adaptive strategies such as CSAq to enhance resilience and productivity (FAO, 2022).

Figure 9. Map to show locations of Mwanza and Mara regions

Mwanza and Mara were selected as study sites due to their economic reliance on fisheries and aquaculture, as well as their diverse farming systems integrating fish farming with crop and livestock production (URT, 2022). Mwanza, known as the "fishing capital" of Tanzania, has a high concentration of fish farmers, aquaculture cooperatives, and fisheries-related industries, making it an important location for assessing CSAq adoption trends and institutional support mechanisms. Mara, on the other hand, is home to both smallholder and commercial fish farms, offering a diverse representation of aquaculture production systems, gender dynamics, and rural development initiatives. These regions provide a rich context for examining the socioeconomic and institutional factors influencing CSAq adoption, particularly among smallholder farmers, women, and youth, who face significant barriers to accessing aquaculture resources and climate adaptation strategies (Adam et al., 2022).

3.2. Research Design

This study adopted a cross-sectional research design, which is widely used in socioeconomic and policy-oriented research to capture data at a single point in time, allowing for the analysis of relationships between CSAq adoption, gender, and institutional factors (Kothari, 2014). The cross-sectional approach was selected because it enables a comprehensive assessment of the factors influencing Climate-Smart Aquaculture (CSAq) adoption, particularly in rural communities where aquaculture practices are evolving in response to climate variability (Babbie, 2021). The study employed a mixed-methods approach, combining quantitative surveys and qualitative key informant interviews to ensure a holistic understanding of CSAq adoption patterns.

3.3. Sampling Procedure

The study was conducted in two purposively selected regions, Mwanza and Mara, due to their significant engagement in aquaculture and relevance to CSAq promotion. Within these regions, specific districts and villages were selected based on the presence of active fish farmers, variation in aquaculture systems, and accessibility of CSAq knowledge and technologies. A multi-stage sampling technique was employed to select respondents.

In the first stage, purposive sampling was used to identify districts and wards with high aquaculture activity. In the second stage, target population was stratified not only by conventional demographics i.e. geographical location, but also by gender and age. This stratification allowed for the deliberate oversampling of women and youth to ensure their adequate representation in the final sample. Lastly, a systematic random sampling approach was applied to select individual fish farmers from registered aquaculture associations, farmer cooperatives, and local fisheries departments. The final sample size consisted of 384 respondents, determined using Cochran's formula (1977) for sample size estimation in large populations using margin of error of 0.05 or 5%, confidence level of 95% and estimated population proportion of 0.5, ensuring statistical representativeness and reliability.

3.4. Data Collection Methods

Primary data were collected using structured questionnaires, and key informant interviews (KIIs). The questionnaires captured demographic characteristics, CSAq adoption levels, socioeconomic factors (education, household size, financial access), and institutional influences (training, extension services, cooperative membership). KIIs were conducted with aquaculture extension officers, government officials, cooperative leaders, and representatives from NGOs supporting CSAq to gain insights into policy frameworks and institutional challenges. KIIs were conducted to explore local perceptions, gender roles, and barriers to CSAq adoption, ensuring that the contextual realities of smallholder fish farmers were incorporated into the analysis.

3.5. Data Analysis

Quantitative data were analyzed using descriptive statistics (frequencies, means, and percentages) and inferential analysis using a Multinomial Logit Model (MNL) to examine the probability of adopting IAA, Polyculture, or Monoculture based on socioeconomic and institutional factors (Greene, 2018). Qualitative data from KIIs and FGDs were transcribed, coded, and analyzed thematically to complement the quantitative findings, providing depth to the interpretation of CSAq adoption patterns.

3.6. Analytical Framework

To examine the socioeconomic, institutional, and gender-related factors influencing CSAq adoption, this study employed both descriptive and econometric analysis techniques. The analytical framework was structured around the Sustainable Livelihoods Framework (SLF), which conceptualizes CSAq adoption as a function of farmers' livelihood assets, institutional support, and external constraints (Scoones, 1998). To empirically assess the probability of adopting different CSAq practices Integrated Aquaculture-Agriculture (IAA), Polyculture, or Monoculture the study applied a Multinomial Logit (MNL) Model, a widely used approach in analyzing categorical decision-making processes in agricultural and aquaculture adoption studies (Greene, 2018; McFadden, 1974).

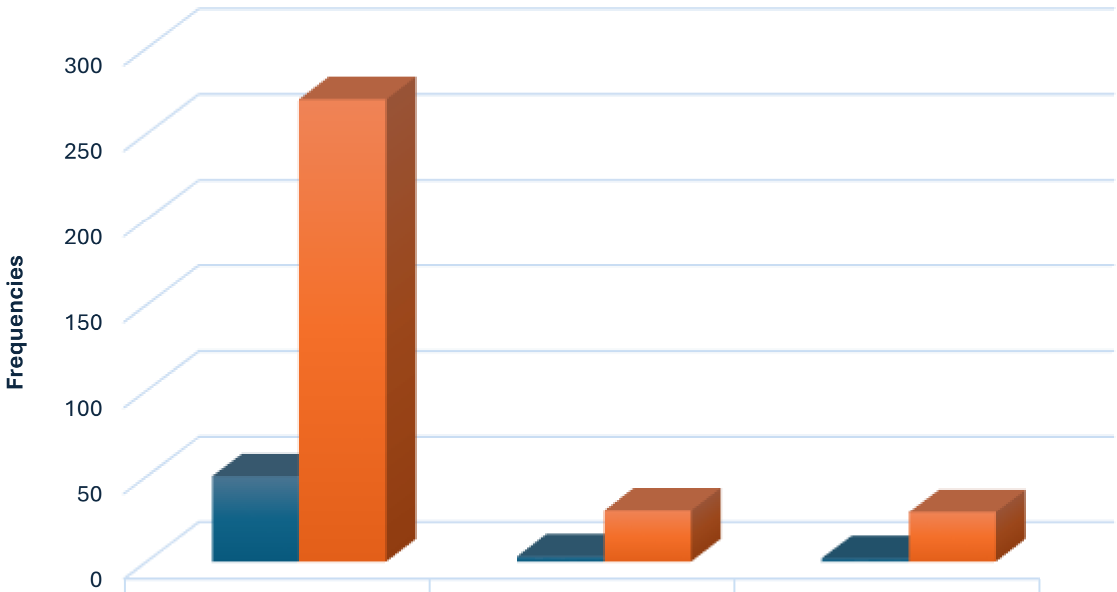
4. Results and Discussion

This section presents and discusses the findings related to gender, socioeconomic, and institutional factors influencing CSAq adoption in Tanzania's Lake Zone. The findings are structured to align with the study objectives, integrating statistical results with theoretical explanations and references to existing literature.

4.1. Descriptive Statistics

4.1.1. Gender Distribution and CSAq Adoption Patterns

Gender plays a critical role in determining the adoption of Climate-Smart Aquaculture (CSAq) practices. The findings reveal a statistically significant disparity in CSAq adoption between men and women ($\chi^2 = 5.24$, $p = .003$), with men significantly more likely to engage in Integrated Aquaculture-Agriculture (IAA) (70.3%) and Polyculture (7.6%), while women remain underrepresented (13.0% in IAA, 0.8% in Monoculture, and 0.5% in Polyculture) as indicated in Figure 3.



	Integrated Aquaculture-Agriculture (IAA)	Monoculture	Polyculture
Female	50	3	2
Male	270	30	29

Figure 10. Gender Distribution of CSAq Adoption

The results confirm persistent gender inequalities in aquaculture, where men are significantly more involved in CSAq practices than women. These findings align with global research on gender roles in fisheries and aquaculture, which suggests that men typically dominate productive aquaculture activities due to their enhanced access to financial resources, land, and technical training (FAO, 2022; (Adam et al., 2022). In Tanzania and many developing countries, women's roles in aquaculture are often restricted to post-harvest processing, marketing, and small-scale fish farming rather than commercial fish farming or farm ownership (Kusakabe & Thongprasert, 2022).

The limited participation of women in CSAq can be attributed to several structural barriers, including limited access to financial resources and land ownership, gendered norms, and lower participation in extension services and CSAq training. The financial exclusion of women limits their ability to invest in IAA and Polyculture, which require capital for infrastructure, fingerlings, and feed (FAO, 2023). Research suggests that women in Tanzania own less than 20% of agricultural land, reducing their access to productive aquaculture resources and thereby hindering their participation in CSAq (World Bank, 2022). Without secure land tenure and financial independence, women are unable to engage in large-scale CSAq production (Hajjar et al., 2020).

Cultural and institutional factors also contribute to the gender disparities observed in CSAq adoption. Traditional gender norms often assign women subsidiary roles in fisheries and aquaculture, limiting their participation in training programs and cooperative leadership (Tiwari & Pinak, 2023). Previous studies have highlighted that women are underrepresented in fisheries decision-making bodies, restricting their influence over policies that could improve CSAq adoption (Kruijssen et al., 2018). Furthermore, women are less likely to access technical knowledge and training opportunities than men, leading to a lower awareness of climate-smart innovations (Maulu et al., 2021). This study confirms previous findings that female farmers are less likely to receive aquaculture training compared to their male counterparts (Babbie, 2021). The lack of knowledge-sharing platforms and training programs tailored for women further exacerbates their exclusion from CSAq adoption.

The gender disparities in CSAq adoption underscore the need for gender-sensitive policies and interventions. Financial inclusion programs targeting women should be expanded to enhance credit accessibility for aquaculture investment. Gender-sensitive extension services and training programs should be introduced to bridge the knowledge gap and empower women in CSAq adoption. Additionally, land tenure reforms should ensure that women have equal access to aquaculture resources to support their engagement in climate-smart aquaculture systems.

4.2 Socioeconomic Factors and CSAq Adoption

Education is a major determinant of CSAq adoption (χ^2 = 132.48, p = .000), with higher education levels correlating with increased adoption of IAA and Polyculture, while Monoculture is more prevalent among less-educated farmers. Education enhances technical knowledge, financial literacy, and risk management skills, enabling better decision-making in aquaculture adoption (Lipper et al., 2014). Farmers with university or diploma education are more likely to engage in complex CSAq systems (IAA and Polyculture), while Monoculture is more common among those with only primary or informal education. Expanding CSAq education programs and extension services could increase adoption rates among less-educated farmers, providing them with the necessary skills to transition from traditional aquaculture to climate-smart practices.

Household size significantly influences CSAq choices (χ^2 = 10.84, p = .021), with larger households adopting IAA more frequently (31.3%) due to greater labor availability. Since IAA requires intensive labor, it is more suitable for households with multiple working members (Obiero et al., 2019; Mdoe et al., 2025). In contrast, smaller households, which may have limited labor resources, tend to engage in Monoculture. This finding suggests that labor availability is a crucial factor in determining the feasibility of adopting labor-intensive aquaculture systems.

Income sources strongly influence CSAq choices (χ^2 = 23.20, p = .000), with farmers who rely solely on fish farming being more likely to adopt IAA than those with off-farm income sources. Since IAA requires substantial investment in infrastructure, feeds, and labor, it is more accessible to financially stable farmers. Those with off-farm income may lack the financial security or technical expertise to transition to climate-smart aquaculture. Expanding credit access and financial support for small-scale farmers could encourage higher CSAq adoption, particularly for those currently reliant on off-farm income sources.

Table 1: Socioeconomic Factors and CSAq Adoption Patterns (n=384)

Variable	Category	Integrated Aquaculture-Agriculture (IAA) (%)	Monoculture (%)	Polyculture (%)	Total (%)	χ^2	p-value
Education Level	Primary	36.5	2.6	1.3	40.4	132.48	.000*
	Secondary	18.2	2.1	0.8	21.1		
	Certificate	1.3	0.3	0.5	2.1		
	Diploma	3.9	2.1	1.3	7.3		
	University	5.2	1.3	2.6	9.1		
	Informal	2.6	1.3	1.8	5.7		
Household Size	Below 3 members	1.8	0.5	0.3	2.6	10.84	.021*
	3-5 members	44.3	9.1	2.6	56		
	Above 5 members	31.3	5.2	4.9	41.4		
Primary Income Source	Fish farming	39.1	2.6	2.1	43.8	23.20	.000*
	Off-fish farming	20.8	6.5	5.5	32.8		
	Both	22.7	0.8	0	23.5		
Age Category	18-25 years	1.6	0.5	0.5	2.6	17.22	.125
	26-35 years	26	2.1	0.8	28.9		
	36-45 years	20.8	2.6	1.3	24.7		
	46-60 years	33.9	3.9	2.6	40.4		
	Above 60 years	5.2	0.8	0	6		

The findings confirm that education level, household size, and income sources significantly influence CSAq adoption. Higher education levels correlate with increased adoption of IAA and Polyculture, while Monoculture is more prevalent among less-educated farmers (χ^2 = 132.48, p = .000). Farmers with university and diploma education are more likely to engage in climate-smart aquaculture systems, aligning with studies that suggest education enhances technical knowledge, financial literacy, and risk management skills in aquaculture (Lipper et al., 2014).

Household size is also a significant determinant of CSAq adoption (χ^2 = 10.84, p = .021). Larger households tend to favor IAA (31.3%), likely due to greater labor availability, while smaller households prefer Monoculture due to labor constraints. These findings support previous research indicating that labor availability is a critical factor in labor-intensive farming systems (Obiero et al., 2019).

Income sources strongly influence CSAq choices (χ^2 = 23.20, p = .000), with farmers relying on fish farming alone being more likely to adopt IAA, while those dependent on off-farm income engage more in Monoculture. Since IAA requires substantial investment in infrastructure, feeds, and labor, it is more accessible to financially stable farmers, whereas those with off-farm income may lack the financial security or technical expertise to transition to CSAq (Mdoe et al, 2024. Expanding credit access and financial support for small-scale farmers could encourage higher CSAq adoption, particularly for those currently reliant on off-farm income sources.

Findings also shows that age category was not statistically significant (p = 0.125) in CSAq practice adoption, suggesting no strong evidence of an age-related effect in CSAq practice adoption. The findings are consistent with Zakaria et al (2020) who found that participation in training programs, rather than age, significantly influenced the adoption of CSA practices in Ghana.

This section highlights the critical role of education, household size, and income stability in determining CSAq adoption. The findings suggest that addressing barriers related to financial access, labor support, and technical training could enhance CSAq adoption across different socioeconomic groups.

4.3. Institutional Factors and CSAq Adoption

Institutional factors such as financial access, extension services, and CSAq training play a critical role in shaping the adoption of Climate-Smart Aquaculture (CSAq) practices. These factors influence farmers' ability to invest in CSAq technologies, acquire knowledge on sustainable practices, and access markets, thereby affecting their decision to adopt Integrated Aquaculture-Agriculture (IAA), Polyculture, or Monoculture. The findings reveal that financial access, extension services, and training participation are statistically significant determinants of CSAq adoption, with p-values below 0.05.

4.3.1. Financial Access and CSAq Adoption

Financial access such as access to credits, formal loans and grants is a key constraint in aquaculture investment, farm expansion, and the adoption of sustainable practices. The findings reveal a statistically significant relationship between financial access and CSAq adoption (χ^2 = 10.26, p = .013), confirming that farmers with better access to credit are more likely to adopt IAA and Polyculture, while those lacking financial access are more likely to practice Monoculture.

Table 2: Financial Access and CSAq Adoption (n=384)

Financial Access	Integrated Aquaculture-Agriculture (IAA) (%)	Monoculture (%)	Polyculture (%)	Total (%)	χ^2	p-value
Yes (Credit Access)	52.6	29.2	18.2	100	10.26	.013*
No (No Credit Access)	42.3	31.9	15.8	100		

The results suggest that farmers with access to credit (52.6%) are more likely to adopt IAA, while those without credit access (31.9%) are more constrained to Monoculture. Limited financial access restricts farmers' ability to invest in fish feed, quality fingerlings, modern pond infrastructure, and risk-mitigation strategies, which are essential for climate-resilient aquaculture. These findings are consistent with previous research indicating that small-scale fish farmers in Africa struggle with credit constraints, leading to reliance on low-cost and traditional aquaculture systems rather than CSAq innovations (FAO, 2022; Obiero et al., 2019).

Research further suggests that women and younger farmers are disproportionately excluded from financial access, exacerbating gender and generational disparities in CSAq adoption. In Tanzania, formal lending institutions prioritize large-scale and male-led aquaculture enterprises, making it difficult for smallholder and female farmers to access the necessary financial resources for CSAq investment (Amare & Simane, 2017). Strengthening financial inclusion policies, providing credit guarantees for smallholder fish farmers, and promoting gender-sensitive credit programs could help bridge this gap.

Expanding financial accessibility through aquaculture credit schemes, microfinance programs, and cooperative lending mechanisms would allow more farmers especially women and youth to transition from traditional Monoculture to more sustainable CSAq models like IAA and Polyculture.

4.3.2. Access to Extension Services and CSAq Adoption

Extension services are fundamental in technology transfer, knowledge dissemination, and skill development, all of which are essential for CSAq adoption. The findings reveal a statistically significant association between extension services and CSAq adoption (χ^2 = 14.89, p = .008), suggesting that farmers who receive extension support are more likely to adopt IAA, while those without extension access engage more in Monoculture.

Table 3: Extension Services and CSAq Adoption (n=384)

Extension Service Access	Integrated Aquaculture-Agriculture (IAA) (%)	Monoculture (%)	Polyculture (%)	Total (%)	χ^2	p-value
Yes (Received Extension Support)	49.3	30	20.7	100	14.89	.008*
No (No Extension Support)	46.8	29.2	14	100		

The results indicate that 49.3% of farmers who received extension services adopted IAA, compared to only 46.8% of those without extension services. Furthermore, Monoculture adoption is higher among farmers who lack extension support (29.2%), highlighting the importance of technical assistance in transitioning towards climate-smart aquaculture systems. These findings align with studies emphasizing that lack of extension services is a major barrier to CSAq adoption in sub-Saharan Africa, as many farmers lack awareness of best aquaculture management practices and climate adaptation strategies (Lind et al., 2022).

Extension services provide fish farmers with training on integrated fish-agriculture systems, sustainable feed management, climate adaptation techniques, and disease prevention, all of which enhance productivity and resilience. However, many smallholder farmers particularly women and those in remote areas face limited access to government extension officers, private advisory services, and farmer cooperatives, further restricting CSAq adoption (Maulu et al., 2021).

To enhance CSAq adoption, government and private sector partnerships should strengthen extension service delivery, ensuring that climate-smart aquaculture knowledge reaches small-scale farmers, women, and youth. Digital platforms, mobile-based advisory services, and community-based extension models could also expand CSAq awareness and uptake.

4.3.3 CSAq Training and Adoption

Formal training in CSAq significantly increases farmers' knowledge, technical competence, and willingness to adopt sustainable aquaculture practices. The findings indicate that CSAq training is strongly associated with CSAq adoption (χ^2 = 19.56, p = .003), with trained farmers more likely to engage in IAA and Polyculture, while untrained farmers are more likely to practice Monoculture.

Table 4: CSAq Training and Adoption (n=384)

CSAq Training	Integrated Aquaculture-Agriculture (IAA) (%)	Monoculture (%)	Polyculture (%)	Total (%)	χ^2	p-value
Yes (Trained)	51.1	29.8	19.1	100	19.56	.003*
No (Untrained)	48.9	28.6	12.5	100		

The results show that 51.1% of trained farmers adopted IAA, compared to 48.9% of untrained farmers. Farmers without CSAq training are more likely to practice Monoculture (28.6%), reinforcing the role of skill acquisition in climate-smart practices. These findings support previous research indicating that lack of technical training prevents farmers from adopting improved aquaculture technologies (FAO, 2022).

Training provides farmers with critical knowledge on pond management, species diversification, climate adaptation techniques, and post-harvest innovations, all of which improve aquaculture sustainability. However, many smallholder farmers, particularly women and young farmers, have limited access to CSAq training, contributing to their exclusion from modern fish farming practices (Babbie, 2021).

Expanding CSAq training through farmer field schools, vocational programs, and community-led initiatives could enhance adoption rates, particularly among marginalized groups. Government agencies, NGOs, and research institutions should collaborate to develop inclusive training programs that integrate climate adaptation strategies, sustainable feed production, and financial literacy to support wider CSAq adoption.

4.4. Results of Multinomial Logit Regression

The study used a multinomial logit regression to identify socioeconomic and institutional factors impacting the adoption of CSAq methods as a dependent variable. The study employed Multinomial logit regression mainly due to two reasons. First the methodology is preferred in adoption modelling (Mdoe et al., 2025b). Secondly, since the dependent variable CSA adoption had three outcomes i.e. Integrated Aquaculture-Agriculture (IAA), Monoculture, and Polyculture which are unordered categories, the model enables the estimation of the probability of each outcome relative to a reference category. This approach allowed researchers to understand the factors influencing each level of adoption. With Integrated Aquaculture-Agriculture being used by the majority of responders (83.3%), it was chosen as the basis outcome. The MNL model used socioeconomic variables such as education level, gender, household size, and primary source of income, while institutional determinants included extension services, CSAq training, and financial access, which was represented by the availability of financial grants and input subsidies.

Multinomial Logit Model used

$$\ln\left(\frac{P(Yi = j)}{P(Yi = base)}\right) = \beta 0j + \beta 1jX1i + \beta 2jX2i + \cdots + \beta kjXki$$

where:

Yi: The dependent variable (CSAq practice) for the ii-th household.
j: The specific CSAq practice (e.g., monoculture, polyculture, and integrated aquaculture-agriculture).
base: The base outcome (integrated aquaculture-agriculture).
X1i, X2i, Xki: The independent variables (e.g., education level, gender, household size, etc.).
β0j, β1j..., βkj: Coefficients to be estimated for each outcome j

Table 5: Multinomial Logit Regression results

Variables	Coefficient	Standard Error	Z	P{Z}	(95% Confi. Interval)	
Monoculture						
Gender	-.49	.35	1.41	0.159	-1.186917	.1943878
Household Size	-.28	.10	-2.83	0.005***	-.4819785	-.0874508
Education Level	-.10	.12	-0.92	0.359	-.3352195	.1216007
Primary Source of Income	.045	.22	0.20	0.839	-.3923498	.4827883
Financial Grant	1.73	.78	2.22	0.026**	.2035401	3.246464
Subsidies Inputs	-.46	.51	-0.90	0.369	-1.461401	.5422969
Extension Services	1.44	.40	3.60	0.000***	.6552123	2.225455
Training Programs	-.17	.30	-0.55	0.585	-.7612193	.429577
Constant	-1.81	1.47	-1.24	0.215	-4.695936	1.057227
Polyculture						
Gender	.62	.52	1.19	0.235	-.4046073	1.648509
Household Size	-.11	.11	-0.94	0.345	-.3277933	.1147476
Education Level	-.48	.14	-3.52	0.000***	-.747261	-.2123474
Primary Source of Income	.326	.25	1.32	0.188	-.1589418	.8115311
Financial Grant	1.26	.97	1.30	0.195	-.6445588	3.165963
Subsidies Inputs	.208	.48	0.44	0.663	-.7301608	1.146836

Variables	Coefficient	Standard Error	Z	P{Z}	(95% Confi. Interval)	
Extension Services	1.04	.43	2.40	0.016***	.1921876	1.891436
Training Programs	.290	.35	0.82	0.410	-.4000123	.9805721
Constant	-4.56	1.87	-2.44	0.015***	-8.231468	-.8933805
Number of obs	351					
LR chi2(18)	58.69					
Prob > chi2	0.0000					
Pseudo R2	0.3886					

, **and* represent significance at 10%, 5% and 1% levels respective.*

The MNL model results indicate that financial grants ($\beta = 1.73$, $p < 0.01$) and extension services ($\beta = 1.44$, $p < 0.01$) significantly increase the likelihood of Monoculture adoption rather than IAA or Polyculture. This finding contrasts with the general expectation that institutional support should facilitate the transition toward climate-smart aquaculture (CSAq) models, such as IAA and Polyculture.

A possible explanation for this trend is that existing financial and extension support programs are not explicitly designed to promote CSAq adoption. In many rural settings, government subsidies, financial grants, and extension training often prioritize single-species (Monoculture) farming due to its perceived lower risk and simpler management requirements (FAO, 2022). Unlike IAA, which requires diverse technical knowledge and infrastructure investments, Monoculture is often viewed as a more straightforward and lower-risk venture for smallholder farmers receiving external support (Amare & Simane, 2017). Furthermore, extension programs in Tanzania's Lake Zone may be providing technical guidance primarily on conventional fish farming rather than on integrated, climate-resilient approaches, unintentionally reinforcing the adoption of Monoculture.

To enhance CSAq adoption, it is essential to redirect financial and extension service support toward diversified aquaculture systems. Policymakers should design aquaculture financing models that explicitly promote investment in IAA and Polyculture, offering incentives for sustainable and integrated fish farming approaches. Additionally, retraining extension officers and updating training curricula to incorporate CSAq principles can ensure that institutional support aligns with climate-smart objectives rather than reinforcing conventional aquaculture models.

Although the descriptive statistics suggested that women have lower CSAq adoption rates, the MNL model finds that gender is not a statistically significant predictor of CSAq adoption choices. This finding does not necessarily indicate that gender is irrelevant to aquaculture adoption, but rather that other structural and institutional factors such as financial access, land tenure, and training play a more decisive role in shaping CSAq adoption patterns.

Previous research highlights that women often face systemic barriers in aquaculture, including limited access to credit, restricted land ownership rights, and lower participation in technical training programs (Kruijssen et al., 2018; FAO, 2023). These constraints can limit their ability to transition from traditional fish farming to more resource-intensive CSAq models, making gender disparities more a function of institutional exclusion rather than intrinsic differences in adoption preferences (Maulu et al., 2023).

The policy implication here is that gender-sensitive interventions should focus on removing structural barriers such as improving women's access to credit, expanding CSAq training programs tailored for female farmers, and ensuring equitable land tenure policies. While the MNL model does not show a direct effect of gender, addressing these underlying constraints would enable more women to participate in CSAq adoption, ultimately fostering a more inclusive and climate-resilient aquaculture sector.

The negative relationship between education level and Polyculture adoption ($\beta = -0.48$, $p < 0.05$), combined with the fact that higher education levels increase the likelihood of IAA adoption, suggests that better-educated farmers prefer integrated and diversified farming models over Polyculture. This result can be explained by the fact that higher education enhances farmers' access to information, technical knowledge, and risk-management skills, which are crucial for understanding and implementing IAA systems (Tiwari & Pinak, 2023). IAA requires a broader knowledge base in ecosystem management, multi-species farming, and water-soil interactions, making it more accessible to farmers with formal education or specialized training in aquaculture. In contrast, Polyculture while more advanced than Monoculture still relies on traditional fish farming techniques, making it less attractive to better-educated farmers who seek more sophisticated and sustainable farming methods.

5. Conclusion and Policy Recommendations

5.1 Conclusion

This study analyzed the influence of socioeconomic, institutional, and gender-related factors on Climate-Smart Aquaculture (CSAq) adoption in Tanzania's Lake Zone, focusing on the choice between Integrated Aquaculture-Agriculture (IAA), Polyculture, and Monoculture. The Multinomial Logit (MNL) model findings revealed that household size, education level, financial grants, and extension services significantly influence CSAq adoption, while gender was not a statistically significant determinant. This suggests that institutional and financial barriers play a more dominant role than gender alone, as women's lower participation in CSAq is primarily linked to limited access to credit, land ownership, and technical training opportunities rather than an inherent lack of interest or capacity. These findings reinforce the need for structural reforms that promote equitable access to resources and institutional support mechanisms to ensure broader CSAq adoption. Education and household size emerged as critical socioeconomic determinants of CSAq adoption. Farmers with higher education levels were more likely to adopt IAA, likely due to increased technical knowledge, risk-management skills, and awareness of the benefits of integrated aquaculture systems. Larger households also showed a higher likelihood of adopting IAA, as they have greater labor availability, which is crucial for managing labor-intensive climate-smart farming systems. In contrast, financial grants and extension services while crucial institutional enablers were found to significantly increase the likelihood of Monoculture adoption rather than promoting CSAq. This finding suggests that current institutional support structures may be reinforcing traditional single-species fish farming rather than incentivizing sustainable, climate-resilient aquaculture models.
The results underscore the urgent need to restructure financial and extension service programs to explicitly promote diversified, climate-smart aquaculture systems rather than reinforcing conventional Monoculture practices. Additionally, gender-sensitive interventions should focus on removing structural barriers such as restricted financial access, land tenure insecurity, and exclusion from technical training programs, which indirectly limit women's participation in CSAq adoption. Addressing these institutional challenges through targeted policy interventions, improved credit access, enhanced CSAq training, and gender-inclusive aquaculture programs will be essential in promoting sustainable, climate-resilient aquaculture adoption in Tanzania's rural economy.

5.2 Policy Recommendations

To enhance Climate-Smart Aquaculture (CSAq) adoption, financial support and extension services must be restructured to promote diversified and climate-resilient systems, such as Integrated Aquaculture-Agriculture (IAA) and Polyculture, rather than reinforcing Monoculture practices. The current funding mechanisms and extension programs tend to favor single-species fish farming, as Monoculture is often perceived as less risky and easier to manage. However, this approach limits farmers' ability to transition to CSAq, which requires integrated resource use, technical knowledge, and diversified income streams. Policies should therefore redesign aquaculture financing schemes, offering targeted incentives for integrated and sustainable aquaculture models, while also ensuring that extension services incorporate CSAq-specific training to equip farmers with the skills necessary to adopt climate-smart innovations.

Additionally, gender-sensitive interventions are crucial to addressing structural barriers that hinder women's participation in CSAq adoption. While gender was not statistically significant in the MNL model, this does not imply the absence of gender disparities in aquaculture as it was found that men had a higher involvement of CSAq practices than women. Instead, it suggests that institutional and financial barriers play a more dominant role in shaping adoption decisions. Policies should focus on improving women's access to credit, secure land tenure, and CSAq training opportunities, ensuring that they can actively participate in climate-resilient aquaculture development. Establishing women-led CSAq cooperatives and mentorship programs could further promote knowledge sharing, financial inclusion, and equitable access to aquaculture resources, ultimately strengthening CSAq adoption among marginalized groups. Integrate CSAq into national climate adaptation policies, ensuring that climate-resilient aquaculture practices are supported through government subsidies and conservation efforts.

References

Adam, R., McDougall, C., Bevitt, K., Freed, S., Gomese, C., Johnson, A., ... & Zaman, T. (2022). Four pathways to achieve gender equality and women's empowerment in small-scale fisheries and aquaculture: *Insights from FISH research.* https://www.worldfishcentre.org

Ahmed, N., Thompson, S., & Glaser, M. (2021). Global aquaculture productivity, environmental sustainability, and climate change adaptability: A review. *Aquaculture International, 29*(1), 85-110. https://doi.org/10.1007/s00267-018-1117-3

Alonso-Población, E., & Siar, S. V. (2018). Women's participation and leadership in fisher folk organizations and collective action in fisheries: a review of evidence on enablers, drivers and barriers. *FAO Fisheries and Aquaculture Circular No. 1159*. Food and Agriculture Organization of the United Nations.

Amare, A., & Simane, B. (2017). Determinants of smallholder farmers' decision to adopt adaptation options to climate change and variability in the Muger Sub basin of the Upper Blue Nile basin of Ethiopia. *Agriculture & Food Security, 6*(64), 1-20. doi:10.1186/s40066-017-0144-2

Babbie, E. (2021). *The practice of social research* (15th ed.). Cengage Learning. https://books.google.com/books?hl=en&lr=&id=lFvjDwAAQBAJ&oi=fnd&pg=PP1&dq=Babbie,+E.+(2021).+The+practice+of+social+research+(15th+ed.).+Cengage+Learning.&ots=I4BS0zaRTa&sig=OMsFTjW5np66eM_x-EbThPfVdME

Carney, D. (1998). Sustainable rural livelihoods: What contribution can we make? *Department for International Development (DFID).* https://www.gov.uk/dfid-research-outputs/sustainable-rural-livelihoods-what-contribution-can-we-make

Chambers, R., & Conway, G. (1992). Sustainable rural livelihoods: Practical concepts for the 21st century. *Institute of Development Studies Discussion Paper, 296, 1-29*. https://www.ids.ac.uk/publications/sustainable-rural-livelihoods-practical-concepts-for-the-21st-century/

DFID (2020). Sustainable livelihoods guidance sheets*. UK Department for International Development*. https://www.gov.uk/dfid

Ellis, F. (2000). Rural livelihoods and diversity in developing countries*. Oxford University Press*.

Food and Agriculture Organization of the United Nations (FAO). (2022). The state of world fisheries and aquaculture: Towards blue transformation*. Food and Agriculture Organization of the United Nations*. https://www.fao.org/publications

Food and Agriculture Organization of the United Nations (FAO). (2023a). Gender equality in fisheries and aquaculture: The status and trends*. Food and Agriculture Organization of the United Nations*. https://www.fao.org/publications

Food and Agriculture Organization of the United Nations (FAO). (2023b). In Brief to The State of Food Security and Nutrition in the World 2023. Urbanization, agrifood systems transformation and healthy diets across the rural-urban continuum. FAO. https://doi.org/10.4060/cc6550en

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change, 43*(3-4), 215-239.

Greene, W. H. (2018). Econometric analysis (8th ed.). *Pearson Education*. https://engineering.purdue.edu/~flm/CE697_files/ealimdep.pdf

Hajjar, R., Ayana, A. N., Rutt, R., Hinde, O., Liao, C., Keene, S., ... & Agrawal, A. (2020). Capital, labor, and gender: the consequences of large-scale land transactions on household labor allocation. *The Journal of Peasant Studies*, *47*(3), 566-588. https://doi.org/10.1080/03066150.2019.1602520

IPCC. (2023). Summary for Policymakers: Synthesis Report. In *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jettah, R. N., Mbasa, B., & Mdoe, C. N. (2024). Enhancing food and nutritional security through gender-disaggregated analysis: A case study of Lake Victoria Shore, Tanzania. *North African Journal of Food and Nutrition Research*, 8(17), 123–134. https://doi.org/10.51745/najfnr.8.17.123-134

Kothari, C. R. (2014). Research methodology: Methods and techniques (3rd ed.). *New Age International*.https://www.google.com/search?cliemt=firefox-b-d&q=https%3A%2F%2F%+www.+research+gate.+net%2F+publi+cation%2F+25187+3585+

Kruijssen, F., Keizer, M., & Giuliani, A. (2018). Collective action and gender dynamics in aquaculture: A review of literature and experiences. *FAO Fisheries and Aquaculture Circular No. 1187*, Food and Agriculture Organization (FAO).

Kusakabe, K., and Thongprasert, S. (2022). *Women and men in small-scale fisheries and aquaculture in Asia*. Rome: FAO.

Lind, C. E., Brummett, R. E., & Ponzoni, R. W. (2022). Small-scale aquaculture and its role in sustainable rural development. *Aquaculture Reports, 24*, 101087. https://doi.org/10.xxxx

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M. & Sessa, R. (2014). Climate-smart agriculture for food security. *Nature Climate Change, 4*(12), 1068-1072.

Maulu, S., Hasimuna, O. J., Haambiya, L. H., Mataa, L., Monde, C., Musuka, C. G., & Phiri, J. (2023). Sustainable aquaculture production in Africa: A review of climate change impacts and adaptation strategies. *Environmental Sustainability, 6*(2), 132-149.

Mbasa, B., Mdoe, C. N., & Jettah, R. N. (2024). Gender and social exclusion in Lake Victoria Basin: A case of Mara and Simiyu Regions, Tanzania. *African Journal of Empirical Research, 5*(1), 216-224. Retrieved from https://ajernet.net

McFadden, D. (1974). Conditional logit analysis of qualitative choice behavior. In P. Zarembka (Ed.), *Frontiers in econometrics* (pp. 105-142). Academic Press.

Mdoe, C. N., Mahonge, C. P., & Ngowi, E. E. (2024). Mapping the trends, knowledge production, and practices of climate-smart aquaculture scholarship: Empirical insights from bibliometric analysis. *Aquaculture, 598(741939)*. https://doi.org/10.1016/j.aquaculture.2024.741939:contentReference[oaicite:1]{index=1}

Mdoe, C. N., Ngowi, E. E., & Mahonge, C. P. (2025). Mapping suitability for climate-smart aquaculture: Geospatial characterization in Tanzania's Lake Zone. *Geomatica*, 77(100046). https://doi.org/10.1016/j.geomat.2024.100046:contentReference[oaicite:0]{index=0}

Mdoe, C. N., Mahonge, C. P., & Ngowi, E. E. (2025b). Drivers and barriers to climate-smart aquaculture adoption: Insights from Mwanza and Mara regions, Tanzania. *Aquaculture International,* 33(1), https://doi.org/10.1007/s10499-025-02028-2

Njaya, F., Heck, S., & Cohen, P. (2021). The intersection of gender and aquaculture development in sub-Saharan Africa. *WorldFish Working Paper No. 2021-05*.

Obiero, K., Shipton, T. A., & Ogello, E. O. (2019). Aquaculture development in Africa: Success stories and lessons learned. *Fish and Fisheries, 20*(6), 1052-1071.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis.IDS Working Paper 72. *Institute of Development Studies*, University of Sussex. https://www.researchgate.net/publications/251873585

Tanzania Meteorological Authority (2023). Climate data report for the Lake Zone region. Dar es Salaam, Tanzania.

Tiwari, P., & Pinak, P. (2023). Climate resilience and aquaculture: Evidence from small-scale fish farmers in developing countries. *Journal of Rural Studies, 92*, 102812.

URT (2022). Tanzania fisheries sector development strategy 2022–2032. *United Republic of Tanzania, Ministry of Livestock and Fisheries*.

World Bank (2022). Blue economy for sustainable development: Unlocking Africa's aquaculture potential. *World Bank Group*.

Zakaria, A., Azumah, S. B., Appiah-Twumasi, M., & Dagunga, G. (2020). Adoption of climate-smart agricultural practices among farm households in Ghana: The role of farmer participation in training programmes. *Technology in Society*, *63*, 101338.