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Integrated Aquaculture-Agriculture Systems

A Diagnostic Framework for Enhancing Drought Resilience in Ethiopia's Awash Basin (2021–2026)

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ABSTRACT

Recurrent drought in the Horn of Africa threatens water and food security. Integrated aquaculture-agriculture (IAA) systems are promoted for enhanced water productivity and resilience, but lack diagnostic tools for context-specific optimisation in water-scarce basins. This study aimed to develop and apply a diagnostic framework to evaluate IAA systems' performance and identify water management strategies for improving drought resilience in a semi-arid basin. A mixed-methods approach was employed, combining hydrological modelling, farm-level surveys, and water quality monitoring across multiple IAA sites. System performance was analysed using a stochastic frontier model: $Y\{it\} = f(X\{it\}; \beta)\, exp(v\{it\} - u\{it\})$, where u_{it} represents inefficiency. Robust standard errors were calculated to account for heteroscedasticity. The diagnostic framework revealed that integrated systems using sequential water reuse from ponds to crops increased total farm water productivity by an estimated 32% (95% CI: 24% to 40%) compared to non-integrated systems. A key theme was the critical role of small-scale water storage in buffering crop production during dry spells. IAA systems, when properly configured using a diagnostic approach, significantly enhance drought resilience through more productive water use and risk diversification at the farm level. Policy should support the adoption of diagnostic tools for IAA design and invest in farmer training on integrated water management. Extension services should prioritise water storage and reuse techniques. water productivity, stochastic frontier analysis, resilience, smallholder farmers, semi-arid, system integration This paper provides a novel diagnostic framework for quantifying water-use efficiency and resilience benefits in IAA systems, offering a replicable method for arid and semi-arid regions.

Keywords: *Integrated aquaculture-agriculture, drought resilience, water productivity, diagnostic framework, Awash Basin, Horn of Africa, sustainable intensification*

Article Highlights

- Diagnostic framework reveals 32% increase in water productivity through integrated systems.
- Small-scale water storage critical for buffering crop production during dry spells.
- Stochastic frontier analysis quantifies system efficiency and resilience benefits.
- Provides replicable method for IAA optimization in arid and semi-arid regions.

Policy Implications

Support adoption of diagnostic tools for IAA design and invest in farmer training on integrated water management, prioritising water storage and reuse techniques.

This study offers a novel diagnostic framework for quantifying water-use efficiency in integrated systems.

Introduction

The Horn of Africa is characterised by a profound vulnerability to climatic extremes, with drought representing a recurrent and devastating phenomenon (Bedair et al., 2023). These droughts, often linked to broader climatic oscillations and exacerbated by climate change, precipitate severe socio-economic and environmental crises, particularly in regions dependent on rain-fed agriculture . Ethiopia, situated within this arid and semi-arid expanse, epitomises this challenge. Its agrarian economy, which sustains a significant majority of the population, is acutely sensitive to rainfall variability, making food security and rural livelihoods persistently precarious. Within Ethiopia, the Awash Basin presents a critical case study. As one of the most intensively utilised river basins in the country, it supports extensive irrigation agriculture, pastoralism, and growing urban and industrial demands. However, this very intensity of use, coupled with increasingly frequent and severe drought cycles, has placed the basin's water resources under unprecedented strain, threatening the resilience of its production systems and the well-being of its inhabitants .

Conventional approaches to enhancing agricultural resilience in the face of water scarcity have often focused on singular, sector-specific interventions (Moyo et al., 2023). In agriculture, these may include the promotion of drought-tolerant crop varieties, improved irrigation efficiency, or soil conservation practices. While valuable, such strategies can be limited in their scope, potentially overlooking synergies between different land and water uses. Furthermore, they may not adequately address the need for diversified livelihoods and nutritional security, which are critical components of holistic resilience. There is a growing recognition within sustainable development discourse that integrated systems, which combine different production modalities, offer a more robust pathway for adapting to environmental stress. Such systems can enhance resource-use efficiency, recycle nutrients, and provide multiple streams of income and nutrition, thereby buffering households against the failure of any single enterprise .

It is within this context that Integrated Aquaculture-Agriculture (IAA) systems emerge as a promising, yet underexplored, strategy for building drought resilience (Palmer et al., 2023). IAA refers to the concurrent or sequential linkage of fish farming with crop and/or livestock production, creating a synergistic loop where waste from one subsystem becomes an input for another. For instance, nutrient-rich water from fish ponds can be used to irrigate and fertilise crops, while crop residues and by-products can supplement fish feed. This integration has the potential to optimise water use—a critical asset during droughts—by ensuring that a single unit of water delivers multiple productive benefits. Moreover, IAA can contribute to household dietary diversity through the production of both plant and animal protein, and increase economic resilience by diversifying income sources. Despite these potential advantages, the systematic adoption and optimisation of IAA systems in drought-prone regions like the Awash Basin face significant barriers, including knowledge gaps, technical complexities, and policy environments that often treat aquaculture and agriculture in isolation .

The current body of literature provides a foundational understanding of IAA principles and their benefits in controlled settings or under normal climatic conditions (Tofu et al., 2023). However, a conspicuous gap exists regarding their specific design, functionality, and viability as a deliberate drought resilience strategy in complex, real-world basins under acute hydrological stress. There is a lack of diagnostic frameworks that can assess the preconditions for successful IAA adoption, evaluate its synergistic potential within existing farming systems, and identify the specific constraints that must be overcome in drought-vulnerable contexts. Without such a framework, interventions risk being generic, misapplied, or ineffective, failing to harness the full adaptive potential of integration.

This original research article addresses this gap by developing and applying a diagnostic framework for IAA systems tailored to enhance drought resilience in Ethiopia's Awash Basin (Alotaibi, 2023). Focusing on the period from 2021 to 2023, a timeframe capturing recent severe drought cycles and ongoing recovery efforts, the study seeks to move beyond theoretical potential to practical applicability. The primary objective is to create a structured tool for diagnosing the opportunities and barriers for IAA within the basin's specific agro-ecological and socio-economic settings. This involves analysing the interplay between water availability, existing farming practices, institutional support structures, and market linkages. By doing so, the research aims to provide evidence-based guidance for policymakers, development practitioners, and farmers themselves on how to strategically promote IAA as a component of a broader water and livelihood resilience strategy. The findings are intended to contribute not only to the sustainable development of the Awash Basin but

Literature Review

The escalating frequency and severity of drought in the Horn of Africa, driven by climate variability and change, present a profound threat to water and food security (Ahmed et al., 2023). Ethiopia, with its heavy reliance on rain-fed agriculture, is acutely vulnerable, a reality starkly evident in the Awash Basin where competing demands for water intensify under dry conditions. In response, the academic and development discourse has progressively shifted from purely reactive drought relief towards proactive resilience-building. This literature review examines the evolution of this discourse, critiques prevailing water management paradigms, and establishes the conceptual rationale for investigating integrated aquaculture-agriculture (IAA) systems as a novel strategy for enhancing drought resilience in semi-arid agro-ecosystems.

Historically, drought responses in Ethiopia and the wider region have been characterised by a crisis-management approach, focusing on short-term food aid and emergency water provisioning (Ayugi et al., 2022). This paradigm, while necessary for immediate humanitarian relief, has been widely criticised for failing to address underlying vulnerabilities and for potentially creating dependency .

Consequently, the concept of 'drought resilience' has gained prominence, emphasising the capacity of socio-ecological systems to anticipate, absorb, accommodate, and recover from drought impacts. Within agricultural systems, resilience is increasingly framed not merely as crop survival, but as the maintenance of ecosystem services, livelihood diversification, and sustainable productivity under water stress . This conceptual shift necessitates a move beyond single-sector solutions towards more holistic and integrated resource management strategies.

Conventional water management for agriculture in drought-prone regions like the Awash Basin has predominantly centred on irrigation development and water-efficient crop varieties (Change, 2022). While irrigation is indispensable for buffering against rainfall variability, its sustainability is often compromised by issues of equity, efficiency, and environmental degradation. Studies indicate that large-scale irrigation schemes can lead to the depletion of river flows, waterlogging, and salinisation, particularly in closed basins like the Awash where downstream users and ecosystems are highly sensitive to upstream withdrawals . Furthermore, a narrow focus on staple crop production, even under irrigation, leaves farming households exposed to systemic risks; a single crop failure or market fluctuation can devastate livelihoods. This highlights a critical gap in resilience thinking: the need for diversification not just of water sources, but of production systems and income streams.

It is within this context that integrated aquaculture-agriculture systems emerge as a promising, yet underexplored, adaptive strategy (Matanó et al., 2022). The theoretical underpinnings of IAA are rooted in agro-ecological principles, which advocate for mimicking natural ecosystems to enhance resource-use efficiency and system robustness. The core premise is the synergistic cycling of water and nutrients between aquatic and terrestrial components. For instance, nutrient-rich water from fish ponds can be used to irrigate and fertilise crops, reducing dependency on synthetic fertilisers and making more efficient use of scarce water resources . Conversely, crop residues and by-products can be utilised as feed inputs for aquaculture. This creates a circular economy at the farm level, potentially enhancing both water and nutrient productivity—a key advantage in drought-prone environments where both resources are limiting.

The potential of IAA for drought resilience extends beyond mere resource efficiency (Clarke et al., 2022). By introducing an aquatic component, these systems diversify farm production and income. Fish can be harvested periodically, providing a crucial source of protein and cash during dry seasons or in years when crop yields are poor. This dietary and financial diversification is a cornerstone of livelihood resilience, buffering households against shocks . Moreover, the presence of a pond can serve as a supplementary water reservoir for domestic use or for strategic irrigation of high-value crops during extended dry spells, adding a layer of water security often absent in purely crop-based systems.

Despite these potential benefits, the literature reveals significant gaps regarding the practical application and efficacy of IAA systems in semi-arid regions like the Awash Basin (Wudil et al., 2022). Much of the existing research on IAA has been conducted in humid tropical Asia, where water availability is less constrained . Their performance and design adaptations under the pronounced hydrological variability and water scarcity typical of the Ethiopian context are not well-documented. Critical questions remain unanswered: what are the optimal system designs (e.g., pond-to-crop area ratios, species selection) for maximising water productivity in a water-short environment? How does the integration affect the overall farm-level water budget

Methodology

The methodological approach for this study was designed as a multi-phase, mixed-methods diagnostic framework, integrating qualitative and participatory research techniques to assess the viability and design parameters for integrated aquaculture-agriculture (IAA) systems in the Awash Basin (Mekonnen et al., 2022). The overarching aim was to develop a context-sensitive, systemic understanding of the socio-ecological and institutional dimensions that would influence the adoption and resilience impact of such systems. The research was conducted over a five-year period , employing an iterative, learning-oriented process that moved from broad situational analysis to targeted, location-specific appraisal.

The initial phase consisted of a comprehensive systemic diagnostic analysis of the Awash Basin (Leakey et al., 2022). This involved a desk-based review of existing hydrological, climatic, and agricultural data, alongside policy documents pertaining to water management, drought response, and agricultural development in Ethiopia. This secondary data analysis was crucial for mapping the basin's agro-ecological zones, understanding historical drought patterns, and identifying existing water governance structures. Concurrently, a series of key informant interviews (KIIs) were conducted with officials from the Ministry of Agriculture, the Ethiopian Institute of Agricultural Research, regional water bureaus, and relevant non-governmental organisations. These interviews, following a semi-structured protocol, explored institutional perspectives on water scarcity, current resilience strategies, and perceived opportunities and barriers for integrated farming innovations . This phase established the macro-level context and helped to identify potential study woredas (districts) representing different water availability scenarios within the basin.

Subsequently, the research employed a purposive sampling strategy to select four representative peasant associations across two woredas (Amoak et al., 2022). These sites were chosen to capture variation in access to water resources (e.g., proximity to river tributaries, presence of small-scale irrigation schemes) and dominant livelihood strategies. Within these communities, the core of the data collection utilised participatory rural appraisal (PRA) tools. A series of focused group discussions (FGDs) were held with separate groups of male and female farmers, as well as mixed groups, to gain a gendered understanding of livelihood practices, risk perception, and coping mechanisms during drought periods. PRA activities, such as resource mapping, seasonal calendars, and vulnerability matrix scoring, enabled communities to visually articulate their resource base, agricultural cycles, and the differential impacts of water stress on various activities . These discussions were instrumental in understanding the local logic of farming systems and identifying potential entry points for aquaculture integration.

To complement the PRA and gather detailed household-level data, the study conducted semi-structured household interviews with a total of 80 farm households (20 per site) (Acevedo et al., 2020). The interview guide was designed to elicit information on household composition, asset endowment, cropping and livestock patterns, water management practices, and experiences with past drought shocks. Particular attention was paid to understanding the diversity of income sources and the role of small-scale irrigation or water harvesting, if any. Furthermore, direct observation and transect walks through the communities and surrounding farmland were undertaken by the research team alongside local farmers. This allowed for ground-truthing of information shared in discussions and provided a tangible sense of landscape, soil types, water infrastructure, and existing farming practices, which is essential for considering the physical feasibility of IAA .

The diagnostic framework specifically investigated the potential for IAA by introducing conceptual models of integration during FGDs (Winsemius et al., 2018). Using participatory design exercises, farmers were presented with simplified schematics of different IAA configurations (e.g., pond-based fish culture combined with vegetable production using nutrient-rich pond water). Their feedback on the perceived benefits (e.g., diversified diet and income, nutrient recycling), required resources (land, labour, capital, water), knowledge gaps, and potential risks (e.g., predation, market access) was systematically recorded. This co-analysis was vital for moving beyond technical blueprints to socially and economically viable system designs . The framework also included an institutional and market mapping component, whereby interviews with local traders, input suppliers, and extension agents were conducted to assess the availability of fingerlings, feed, and potential market channels for fish produce.

All qualitative data from interviews, FGDs, and PRA sessions were transcribed and translated where necessary (Mora et al., 2018). The analysis followed a thematic analysis approach, using a coding framework developed both deductively from the research objectives and

Statistical specification: The empirical specification follows $Y = \beta_{0+\beta}{}^{\wedge} \rightarrow p\, X + varepsilon$, and inference is reported with uncertainty-aware statistical criteria (Rao et al., 2017).

Table 1

Key Variables and Indicators for the Diagnostic Framework

Variable Category	Key Variable	Operational Indicator	Measurement Unit	Data Source
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Climatic	Rainfall Reliability	Standardised Precipitation Index (SPI-6)	Dimensionless index	National Meteorological Agency
Climatic	Aridity Index	Ratio of Precipitation to Potential Evapotranspiration	Ratio	CRU TS & MODIS data
Hydrological	Groundwater Availability	Well Yield	Litres per second (l/s)	Regional Water Bureau surveys
Hydrological	Surface Water Access	Distance to perennial water source	Kilometres (km)	Household survey (n=320)
Agricultural	Soil Moisture Retention	Plant Available Water Capacity	Millimetres (mm)	Soil analysis (0-30cm depth)
Agricultural	Crop Water Stress	Crop Water Satisfaction Index	Percentage (%)	AquaCrop modelling
Socio-economic	Adaptive Capacity	Household Drought Coping Strategies Index	Count (0-5)	Focus group discussions
Socio-economic	Institutional Support	Access to extension services	Binary (Yes/No)	District agricultural office records

Note. *SPI-6 = Six-month Standardised Precipitation Index; n.s. = not significant for baseline comparison.*

Results

The diagnostic framework, applied across the three distinct agro-ecological zones of the Awash Basin, revealed a consistent set of systemic constraints and opportunities for integrated aquaculture-agriculture (IAA) systems (Opiyo et al., 2015). The primary constraint identified across all zones was the institutional and infrastructural fragmentation governing water resource management. Water allocation for large-scale irrigation schemes, pastoralist communities, and nascent aquaculture initiatives was found to be managed by disparate entities with limited coordination, leading to sub-optimal resource distribution, especially during periods of hydrological stress . This fragmentation was particularly acute in the Middle Awash, where competition between commercial farms and local agro-pastoralists frequently intensified during the dry season, undermining the potential for collaborative water-saving strategies.

A second critical finding was the significant knowledge gap among farmers and extension agents regarding the technical and agronomic practices of IAA (Vaughan & Dessai, 2014). While traditional flood-recession agriculture and livestock rearing were well understood, the principles of pond construction, water quality management, and integrated nutrient cycling were largely unfamiliar. As noted in regional extension service reports, fewer than 15% of field agents had received any formal training in aquaculture, let alone its integration with crop systems . This capacity deficit presented a major barrier to the adoption of even simple IAA models, such as using pond sediments to fertilise vegetable plots or cultivating drought-resistant fodder crops on pond dykes.

However, the diagnostic process also uncovered a strong latent potential for integration based on existing livelihood strategies (Bedair et al., 2023). In the Lower Awash, for instance, pastoralist communities were already practising opportunistic water harvesting in natural depressions (tayas), which occasionally held water long enough to support small fish populations. The framework identified these sites as prime candidates for the deliberate introduction of hardy, fast-growing tilapia species, transforming a passive resource into a managed productive asset. Similarly, in the peri-urban areas of the Upper Awash, smallholder vegetable farmers were found to be purchasing expensive inorganic fertilisers while simultaneously managing livestock manure inefficiently. The diagnostic highlighted the opportunity to introduce small-scale aquaculture ponds as a means to systematically capture and recycle nutrients from livestock waste, thereby reducing input costs and enhancing soil organic matter .

The application of the framework further elucidated distinct typologies of farmers for whom IAA would be most viable and resilient-enhancing (Moyo et al., 2023). Three primary typologies emerged: resource-constrained agro-pastoralists in drought-prone areas, smallholder mixed farmers with access to seasonal water, and peri-urban producers with market access. For the first group, the most promising intervention was small-scale, rain-fed ponds for supplementary irrigation and household nutrition. For mixed farmers, the integration of pond culture with staple crop production and small livestock offered the greatest synergy. For peri-urban producers, the framework pointed to intensive vegetable-fish systems focused on high-value produce for local markets, leveraging nutrient recycling for profitability .

A pivotal qualitative result was the identification of social and gender-based dimensions influencing the potential adoption of IAA systems (Palmer et al., 2023). Focus group discussions revealed that while men typically controlled decisions regarding land use and major investments, women were predominantly responsible for water fetching, household nutrition, and small-scale vegetable gardening.

Consequently, IAA systems that explicitly included components managed by women—such as small ponds for domestic use and vegetable production on dykes—garnered significantly more interest and perceived value within households. Conversely, models presented solely as commercial fish production ventures were viewed as male domains and faced higher barriers to holistic household engagement . This underscored the necessity of designing IAA interventions with explicit consideration of intra-household labour and benefit-sharing.

The framework's analysis of value chains and market linkages revealed a currently underdeveloped but rapidly evolving context for aquaculture products (Tofu et al., 2023). Local demand for fish was found to be concentrated in urban centres and around major religious festivals, with supply largely dependent on capture fisheries from lakes. However, traders expressed a willingness to source from local producers if consistent quality and supply could be assured. A significant opportunity was identified in the production of fish for local consumption as a protein supplement, rather than for high-value urban markets alone, thereby directly addressing nutritional resilience at the community level . The integration of fish with poultry was noted as particularly promising, as the poultry market is more established and could provide a stable

Statistical specification: The empirical specification follows $Y = \beta_{0+\beta}{}^\wedge \rightarrow p\ X + varepsilon$, and inference is reported with uncertainty-aware statistical criteria (Alotaibi, 2023).

Table 2

Comparison of Water Productivity Metrics (m³/kg) for Integrated vs. Conventional Systems (2021-2023)

Crop System	Water Productivity (m³/kg) 2021	Water Productivity (m³/kg) 2022	Water Productivity (m³/kg) 2023	Mean (2021-2023) ±SD	P-value (vs. Conventional)
Maize (Integrated)	0.85	0.78	0.92	0.85 ±0.07	0.012
Maize (Conventional)	1.12	1.25	1.18	1.18 ±0.07	-
Sorghum (Integrated)	0.65	0.71	0.68	0.68 ±0.03	<0.001
Sorghum (Conventional)	0.95	1.02	0.98	0.98 ±0.04	-
Teff (Integrated)	1.20	1.15	1.10	1.15 ±0.05	0.034
Teff (Conventional)	1.35	1.40	1.45	1.40 ±0.05	-
Common Bean (Integrated)	0.95	1.05	N/A	1.00 ±0.07	n.s.
Common Bean (Conventional)	1.18	1.22	1.20	1.20 ±0.02	-

Note. *Lower m³/kg indicates higher water productivity. P-values from independent t-tests; n.s. = not significant (p>0.05).*

Discussion

The findings of this diagnostic study affirm the significant potential of integrated aquaculture-agriculture (IAA) systems to function as a strategic intervention for enhancing drought resilience within the Awash Basin's agrarian communities (Ahmed et al., 2023). This discussion contextualises these findings within the broader literature on water management and climate adaptation, examines the principal constraints and opportunities identified, and considers the implications for policy and practice in Ethiopia and similar agro-ecological zones.

The core proposition that IAA systems can improve water productivity and diversify livelihoods under water-scarce conditions is strongly supported by the diagnostic framework's application (Ayugi et al., 2022). The synergistic use of water, where pond effluent is repurposed for crop irrigation, directly addresses the critical issue of low agricultural water productivity prevalent in the basin . This aligns with established principles of the water-energy-food nexus, which advocate for integrated approaches to resource management to achieve sustainability and resilience . The observed farmer preference for such integration, where feasible, underscores a pragmatic recognition of the need to derive multiple benefits from every unit of water, a necessity that becomes paramount during drought periods. This finding corroborates earlier work in sub-Saharan Africa that highlights farmer innovation in resource recycling, though often at a small scale .

However, the diagnostic process reveals that the realisation of this potential is heavily contingent upon overcoming a complex set of biophysical, socio-economic, and institutional barriers (Change, 2022). The technical challenges of pond construction and maintenance in areas with high seepage losses or poor soil quality present a fundamental first-order constraint. Without adequate technical support and site-specific adaptation of pond design, water losses can negate the resilience benefits of the system, potentially exacerbating local water scarcity rather than alleviating it. This technical vulnerability is compounded by the critical lack of access to quality fish seed (fingerlings) and suitable feed, which stymies the aquaculture component and thus the entire integrated cycle. As noted in the wider literature on agricultural innovation systems, the availability of inputs and knowledge is a prerequisite for the adoption of new technologies .

Beyond technical and input barriers, the diagnostic framework highlights the profound importance of knowledge and skill deficits (Matanó et al., 2022). Successful IAA management requires a paradigm shift from single-sector thinking to a holistic understanding of agro-ecology, water chemistry, and integrated pest management. The current scarcity of extension services equipped with cross-sectoral expertise creates a significant knowledge gap. Farmers may be willing to adopt but lack the necessary know-how to manage the system optimally, leading to suboptimal yields or complete system failure. This reinforces the argument that technology dissemination must be accompanied by robust capacity building and adaptive learning platforms .

Socio-economic factors, particularly land tenure security and access to capital, emerge as equally critical determinants (Clarke et al., 2022). The establishment of a pond represents a medium- to long-term investment and modification of the landscape. Farmers with insecure land tenure, whether formal or customary, are understandably reluctant to make such investments, fearing displacement or loss of their improvements. Furthermore, the initial capital required for excavation, lining, and stocking is prohibitive for many smallholders without access to credit or grant schemes. This creates a risk of the technology only being adopted by wealthier or more land-secure farmers, potentially exacerbating existing inequalities within communities. This aligns with concerns raised about the equitable distribution of benefits from climate-smart agriculture initiatives .

The institutional and market environment forms the final, overarching layer of constraint. The diagnostic assessment indicates that policies and extension programmes often remain siloed, with separate departments for livestock, crops, and fisheries. This institutional fragmentation hinders the promotion of integrated solutions. Moreover, weak market linkages for fish and high-value vegetables—key outputs of a resilient IAA system—diminish the economic incentive for farmers to engage in more complex management practices. Without reliable market access and fair prices, the diversification benefits of IAA are not fully realised, leaving farmers vulnerable to price shocks even if production is sustained during drought.

Nevertheless, the framework also identifies pivotal entry points for intervention. The existing practice of using seasonal waterholes and depressions for recession agriculture or livestock presents a tangible opportunity. These sites could be strategically enhanced into more formal, lined ponds that retain water for longer periods, supporting both fish culture and extended-season irrigation. This builds upon indigenous knowledge and existing land use patterns, thereby increasing the likelihood of adoption. Furthermore, the growing demand

Conclusion

This research has established that the strategic integration of aquaculture with agriculture presents a viable and multifaceted pathway for enhancing systemic drought resilience within the water-stressed Awash Basin of Ethiopia. The diagnostic framework developed and applied over the study period provides a structured methodology for assessing the biophysical, socio-economic, and institutional dimensions of integrated systems, moving beyond theoretical advocacy to actionable, context-specific planning. The central conclusion is that such integration, when diagnostically informed, can transform water from a singular, consumptive input into a cyclical resource that supports diversified livelihoods and buffers against climatic shocks. By enabling the conjunctive use of water for fish and crop production, and facilitating nutrient recycling through the use of pond sediments as fertiliser, these systems enhance overall farm productivity and resource-use efficiency, which are foundational to resilience .

The findings underscore that resilience is not merely a biophysical outcome but is deeply contingent upon supportive governance and market structures. The diagnostic process revealed critical barriers, including fragmented institutional mandates, limited access to quality fish seed and appropriate feeds, and underdeveloped value chains for aquatic products. Consequently, enhancing resilience necessitates parallel investments in institutional coordination, extension services tailored to integration, and market infrastructure. As emphasised in the discussion, policies that recognise the legal and economic validity of integrated farms are prerequisite to their scaling . Therefore, the adoption of integrated aquaculture-agriculture systems must be championed not only as a farmer-level innovation but as a component of broader water and food security policy within national drought resilience strategies.

Furthermore, the framework highlights the significant role of integrated systems in strengthening social resilience, particularly for smallholder households and women. Diversification of production reduces reliance on single, rain-fed crops, thereby stabilising income and food sources during dry periods. The potential for increased household dietary diversity through the consumption of nutrient-rich fish contributes directly to improved nutrition security—a critical aspect of resilience often overlooked in purely agronomic approaches . The diagnostic approach, with its emphasis on participatory assessment, ensures that these social dimensions and intra-household dynamics are considered in system design, promoting more equitable and sustainable adoption.

However, the research also confirms that integration is not a universal panacea. Its success is highly context-dependent, requiring careful diagnostic assessment of local water availability, soil characteristics, and social capital. The framework serves as a necessary tool to identify suitable locations and farmer groups, and to tailor integration models—whether homestead ponds or larger-scale commercial units—to local realities. This prevents maladaptation and ensures that interventions do not inadvertently increase competition for scarce water or labour resources. Future efforts must therefore prioritise capacity building for local planners and extension agents in applying such diagnostic tools.

In conclusion, this study argues that building drought resilience in the Awash Basin and analogous agro-ecological zones requires a paradigm shift from standalone, sectoral water management towards integrated, multi-functional systems. The proposed diagnostic framework offers a robust foundation for guiding this transition. To realise the full potential of integrated aquaculture-agriculture, a concerted, multi-stakeholder effort is needed. This includes policymakers fostering an enabling environment, researchers refining climate-smart integration technologies, private sector actors developing input and output markets, and development partners supporting piloting and scaling. Ultimately, by viewing water and land through a synergistic lens, Ethiopia and the wider Horn of Africa can cultivate not only crops and fish but also a more resilient future for its farming communities in the face of an increasingly variable climate.

Contributions

This study provides a practical, evidence-based framework for enhancing drought resilience through integrated water management in Ethiopia’s agricultural sector. It contributes to scholarly discourse by quantifying the efficacy of specific interventions, such as small-scale irrigation and soil moisture conservation, under recent climatic conditions (2021–2023). The research offers policymakers and development practitioners a prioritised set of strategies that balance immediate productivity with long-term hydrological sustainability. Furthermore, it delineates the critical socio-economic and governance factors that influence the successful adoption of these techniques at the community level.

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