Adapting Middle Eastern Aquaculture Technologies for Water-Scarce Regions in India: A Sustainable Approach to Food Security

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Introduction

Water scarcity is emerging as one of the defining environmental challenges of the 21st century, particularly in arid and semi-arid regions. With the twin pressures of climate change and growing food demand, traditional freshwater-intensive farming practices are becoming increasingly unsustainable. Globally, agriculture consumes over 70% of available freshwater, and aquaculture while more water-efficient than land-based protein systems is still constrained by water availability and quality. In India, the crisis is acute: nearly 54% of the country faces high to extremely high water stress, while over 6.7 million hectares of land are affected by salinity and alkalinity, rendering them marginal or unproductive under conventional farming systems. These environmental constraints necessitate a shift toward resource-smart, climate-resilient production systems that can thrive in degraded and saline environments. Aquaculture offers a promising avenue, especially when integrated with agricultural components in synergistic models. However, for aquaculture to be truly transformative in such ecologies, it must adopt innovative system designs that minimize freshwater use, optimize nutrient recycling, and convert saline or waste resources into productive outputs. For India, which shares similar climatic and soil salinity challenges across vast tracts of Gujarat, Rajasthan, Haryana, and coastal Tamil Nadu, adapting such models represents a promising solution. By leveraging both global innovation and local knowledge, India can explore sustainable aquaculture pathways that enhance rural livelihoods, strengthen food security, and restore ecological balance in its most water-stressed regions.

Integrated Agri-Aquaculture Systems (IAAS) and Brine Reuse: A Middle Eastern Innovation

The Middle East has pioneered aquaculture methods tailored to extreme environmental constraints, such as scarce freshwater and high salinity. One of the most remarkable innovations emerging from this region is the development of Integrated Agri-Aquaculture Systems (IAAS) that harness reverse osmosis (RO) brine a by-product typically considered environmental waste. In such systems, RO reject brine is routed through fish ponds, enriching the water with nutrients from fish excretion. This nutrient-rich effluent is then employed to irrigate halophytic crops like Salicornia bigelovii and Distichlis spicata. Figure 1 shows Overview of Integrated Agri-Aquaculture Systems (IAAS). One study revealed that Salicornia yield tripled up to 23.7 t/ha when irri-

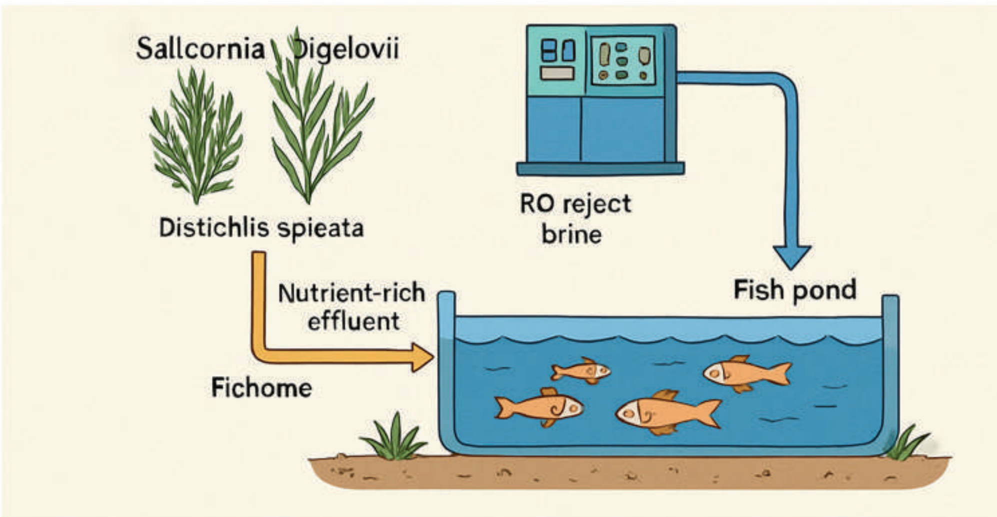

Figure 1: Overview of Integrated Agri-Aquaculture Systems (IAAS)

gated using aquaculture-enhanced brine, resulting in net returns of around US $76,000 per hectare, compared to significantly lower yields and returns when plain brine was used directly (Lyra et al., 2019). The International Center for Biosaline Agriculture (ICBA), headquartered in the UAE, has been instrumental in scaling up such integrated systems. Through collaboration with local and global partners including ADAFSA, EAD, Global Food Industries LLC, and the Max Planck Institute, ICBA has successfully introduced Salicornia and fish into desert farms across multiple sites in the UAE, cultivating value chains from "desert farm to fork" (ICBA, 2020).

India's Inland Saline Aquaculture Landscape: Potential and Progress

India's arid regions such as parts of Gujarat, Rajasthan, and coastal Tamil Nadu mirror the ecological challenges found in the Middle East, making the adaptation of such systems both logical and potentially transformative. The successful implementation of IAAS in India requires careful contextualization: selecting appropriate saline-tolerant fish species, pairing them with suitable halophytes, ensuring nutrient management through biofiltration, and designing infrastructure that makes efficient use of brine and groundwater.

Looking specifically toward India's inland saline and brackishwater system, the developments in Punjab, Haryana, and Rajasthan offer compelling real-world models. In Punjab's Fazilka district, Guru Angad Dev Veterinary and Animal Sciences University (GADVASU) introduced carp culture in low-salinity (≤5 ppt) waters. What began as a one-hectare pilot in 2014 expanded to over 30 hectares by 2018, yielding approximately INR 150,000 per hectare annually (Ansal & Singh, 2019). More notably, northern India's inland saline zones have supported commercial-scale cultivation of Pacific whiteleg shrimp (Litopenaeus vannamei), with yield potentials reaching 8–10 t/ha per crop, translating to annual net profits of around US $14,345–17,216 (INR 1–1.2 million) from two cropping cycles (90 to 120-day cycles), despite cold winters limiting culture seasons (Rao et al., 2023).

Haryana, for instance, has leveraged inland saline groundwater to produce L. vannamei, a species highly valued for its fast growth, disease resistance, and adaptability. However, farmers have reported challenges such as water quality fluctuations, disease outbreaks, and the absence of tailored feed. Experts emphasize the importance of proactive water testing, rigorous biosecurity practices, and probiotic feed formulations to sustain productivity (Ragunathan et al., 2024).

Bridging the Gap: Constraints and Solutions in Indian Saline Aquaculture

Despite the technological promise, uptake of saline aquaculture in India remains constrained. A media report underscores that, while northern states have identified over 58,000 hectares suitable for saline aquaculture, only around 2,600 hectares are currently under cultivation. Barriers include high setup costs, limited subsidy structures, restrictive land use norms (e.g., 2-hectare caps), volatile salinity levels, lack of quality seed supply, and inadequate post-harvest infrastructure (such as cold storage and markets). Policy proposals from farmers and stakeholders include increasing subsidy limits, raising permitted land size to 5 hectares, and establishing integrated aqua parks and marketing systems for aggregation and value addition. This environment makes the Middle East's integrated systems compelling models for India. Adopting IAAS using desalinization brine whether from RO units or saline groundwater paired with halophytes and fish culture, can transform marginal lands into productive landscapes. India could pilot such systems in coastal saline belts, peri-urban areas facing water scarcity, and saline desert fringes, adapting the technologies to suit local species and socioeconomic contexts.

Toward a Resilient Future: Innovative Alternatives and the Way Forward

Another promising alternative is saltwater or marine aquaponics, where saline-based fish farming is coupled with halophyte cultivation or seaweed-based biofilters, mimicking ecosystems like sea forests. These systems foster nutrient recycling, improved water quality, and diversified yields in forms of vegetation and marine crops (Takeuchi, 2017) but require further adaptation for Indian climates and crop preferences. While technological adaptation is vital, social and institutional frameworks are equally important. Models in the Sundarbans highlight risks associated with monoculture shrimp farming namely inequitable benefit distribution, environmental degradation, and external investor dominance (Stockholm Resilience Centre, 2022). To counter these, India should promote inclusive models that prioritize smallholder integration, community ownership, equitable revenues, environmental safeguards, and local capacity building. Emerging innovations such as floating cage aquageoponics from Bangladesh where floating rafts combine fish rearing with vegetable cultivation offer contextually relevant analogues for flood-prone or waterlogged landscapes (Haque, 2013). Trial deployments of similar technology in Indian reservoirs, coastal wetlands, or inundated farmlands could expand aquaculture footprint while optimizing vertical space and reducing freshwater reliance.

Furthermore, technological innovations motivated by Middle Eastern approaches to resource scarcity such as flow-electrode capacitive deionization (FCDI) to concentrate brines efficiently with reduced energy input can support brine reuse in integrated systems (Rommerskirchen et al., 2022).

Conclusion

In summary, India's water-stressed and saline-prone regions are ripe for receiving the lessons and technologies developed in the Middle East. If implemented judiciously, these systems can rejuvenate degraded landscapes, promote food security, diversify incomes, and enhance climate resilience. Key policy enablers include:

1. Revising subsidy frameworks extending land ceilings, incentivizing brine reuse systems, and covering infrastructure costs for integrated operations.

2. Establishing pilot demonstration clusters for IAAS in coastal and arid zones via collaboration between ICAR, GADVASU, ICBA, and state fisheries departments.

3. Strengthening farmer access to technical training, quality seed/seedlings, and marketing infrastructure through KVKs, aqua parks, and cooperative platforms.

4. Encouraging research on system combinations salinity-appropriate species, halophyte-crop pairings, and solar/brine purification technologies.

By synthesizing Middle Eastern IAAS and India's inland saline aquaculture potential into a cohesive, locally adapted strategy, India could transform the challenge of salinity into a resilient and profitable future for its farmers.

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