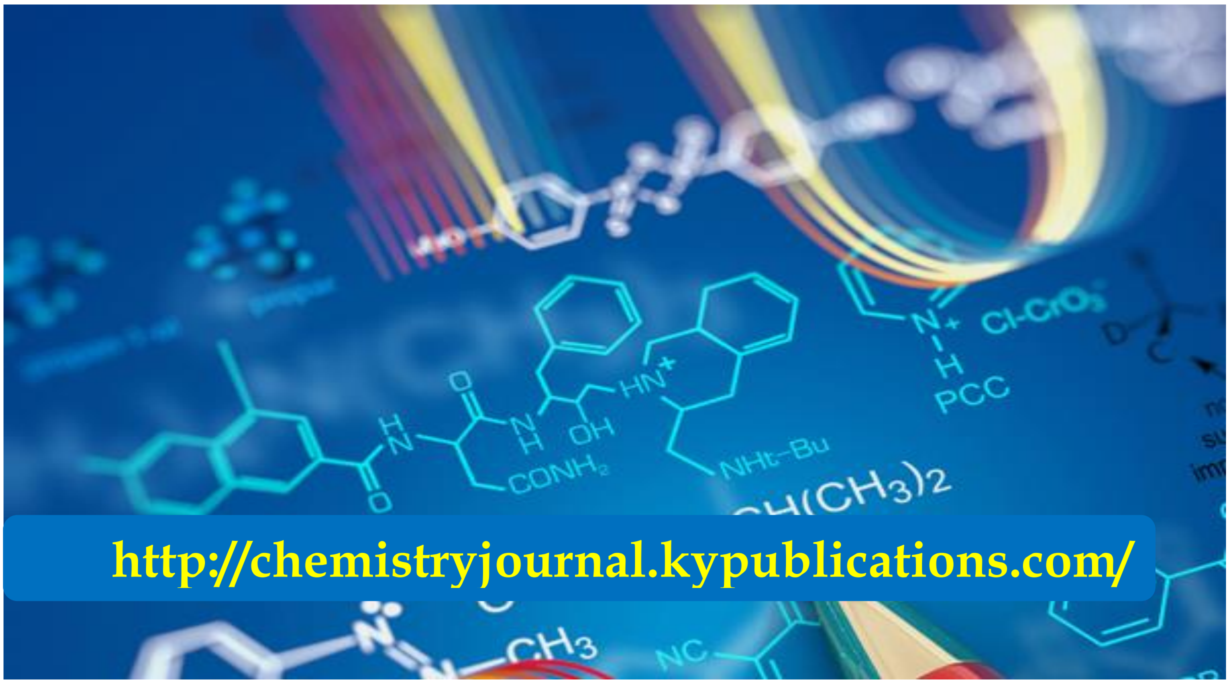

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Review Article

Aquaculture practices in rural ponds of South Bengal, West Bengal, India

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ABSTRACT

This article examined aquaculture practices in rural ponds of South Bengal (the southern districts of West Bengal), India. It described the historical development of pond-based fish culture, typical pond types and designs, species selection and polyculture practices, pond preparation and management, water quality parameters and their seasonal dynamics, feeding strategies and feed resources, disease occurrence and health management, integration with agriculture and livestock, socio-economic significance, gender and labour roles, institutional support and market linkages, environmental impacts, constraints faced by smallholder farmers, and practical recommendations for sustainable intensification. The narrative was written in the past tense and drew on general empirical knowledge and the known farming context of the Gangetic plains, providing a comprehensive perspective intended for researchers, extension workers, policy-makers and pond farmers.
Keywords: Aquaculture, Rural Ponds, South Bengal, Fish Farming, Livelihoods, Sustainable Practices.

1. Introduction

Aquaculture had emerged as one of the most significant components of rural livelihoods in South Bengal, West Bengal, due to its potential to ensure food security, generate employment, and enhance income for smallholder farmers. The southern part of West Bengal, comprising districts such as South 24 Parganas, North 24 Parganas, East Midnapore, Howrah, Hooghly, and Nadia, had long been recognized for its extensive network of ponds and wetlands that supported diverse aquatic ecosystems and fish production (Bhaumik, 2015). Traditionally, pond-based aquaculture had been practiced as a subsistence activity, where rural households maintained small ponds adjacent to homesteads for domestic consumption. However, with the increasing demand for fish and declining capture fisheries, aquaculture transitioned into a semi-commercial and commercial enterprise (Saha & Mitra, 2018).

Fish had occupied a central position in the dietary habits and cultural identity of the Bengali population, making aquaculture a vital socio-economic activity. The per capita fish consumption in West Bengal had been among the highest in India, which consequently stimulated the rapid expansion of pond culture (Department of Fisheries, Government of West Bengal, 2021). The region's favourable tropical climate, fertile alluvial soil, and abundant water resources provided an ideal environment for the development of aquaculture (Banerjee et al., 2016). The presence of perennial ponds, beels, and wetlands enabled rural farmers to adopt a variety of production systems ranging from extensive to semi-intensive polyculture.

Pond aquaculture in rural Bengal was predominantly characterized by the culture of Indian Major Carps (IMCs) such as *Catla catla*, *Labeo rohita*, and *Cirrhinus mrigala*, often supplemented with exotic species like *Cyprinus carpio* (common carp) and *Ctenopharyngodon idella* (grass carp) to utilize diverse ecological niches (Chakraborty & Das, 2019). The polyculture system was preferred because it maximized resource utilization, improved productivity, and enhanced profitability under low-input conditions. Farmers commonly practiced traditional pond preparation techniques involving drying, liming, and manuring to improve soil and water fertility (Singh et al., 2017).

In rural South Bengal, aquaculture not only contributed to food production but also played a pivotal role in livelihood diversification and employment generation, particularly for landless and marginal farmers (Mandal et al., 2020). Women's participation in fish feeding, pond maintenance, and small-scale processing activities reflected the gender-inclusive nature of this occupation (Das & Pal, 2018). Moreover, aquaculture in homestead ponds often integrated with agriculture and livestock production, forming a sustainable farming system where nutrient recycling and water use efficiency were maximized (Bhattacharya et al., 2015).

However, despite its socio-economic importance, aquaculture in rural South Bengal faced multiple challenges. Poor access to quality fish seed, irregular water supply, disease outbreaks, environmental degradation, and lack of financial and technical support hindered sustainable development (Manna et al., 2019). Seasonal fluctuations in rainfall and salinity intrusion in coastal districts further complicated pond management practices (Mitra et al., 2020). Limited availability of formulated feed, dependency on traditional inputs such as rice bran and oil cake, and fluctuating market prices restricted the profitability of small-scale farmers (Ghosh & Alam, 2021).

Government and non-government organizations had introduced several initiatives, such as the *Blue Revolution Mission* and the *Pradhan Mantri Matsya Sampada Yojana (PMMSY)*, to enhance fish productivity and promote scientific aquaculture practices (Department of Fisheries, 2021). These programs aimed to improve seed quality, expand hatchery infrastructure, provide technical training, and facilitate access to markets and financial assistance. The introduction of Geographic Information Systems (GIS) and Remote Sensing tools had also helped identify suitable aquaculture zones and monitor pond health more effectively (Patra et al., 2020).

Understanding the current aquaculture practices in rural ponds of South Bengal was, therefore, essential to assess their ecological, economic, and social implications. Such knowledge provided insights into the sustainability of local production systems and their capacity to adapt to environmental and economic changes. This study thus focused on the traditional and modern pond aquaculture techniques, their management practices, the socio-economic significance of fish culture, and the constraints faced by rural farmers in South Bengal. The main objectives of this study were to analyze the traditional and scientific aquaculture practices followed in rural ponds of South Bengal, West Bengal, to identify the types of ponds, cultured species, and pond management techniques adopted by small and marginal farmers, to examine the socio-economic importance of pond aquaculture in improving livelihoods and nutritional security of rural households, to evaluate the major challenges and constraints faced by farmers in sustaining pond aquaculture practices and to suggest measures for sustainable and environment-friendly aquaculture development in rural South Bengal.

2. Historical background and socio-cultural context

Pond culture in South Bengal had deep historical roots. Rural households traditionally dug small ponds (locally called *dighi*, *pokhri* or *talao*) for multiple purposes — irrigation, domestic water supply, fish culture and livestock watering. Fish rearing in these ponds had been integrated into household economies, with common carp, indigenous cyprinids (such as rohu and catla), catfishes and small indigenous species forming the backbone of production. Cultural practices around fish consumption and pond rights were well-established; fish were consumed on important occasions and pond ownership and access were often linked to customary land tenure.

During the post-independence period, government extension programs and cooperative movements had promoted improved fingerling production, simple pond management techniques and cooperative marketing. In the late 20th and early 21st centuries, the Green Revolution and intensification of agriculture affected pond systems: conversion of wetlands to cropland, increased use of agrochemicals and changing water regimes introduced new challenges as well as opportunities for integrating fish culture with cropping systems.

3. Study area characteristics (South Bengal)

Although South Bengal encompassed several districts with local variation, the recent study was conducted in Howrah, Hooghly, Purba and Paschim Medinipur districts where common environmental and socio-economic characteristics had shaped pond aquaculture practices. The area had a tropical wet-dry climate with monsoon rains concentrated from June to September. Alluvial soils derived from the Ganges-Brahmaputra-Meghna system prevailed, with many low-lying tracts and floodplains. Groundwater levels and surface water availability allowed for pond construction and seasonal water exchange. Rural households were generally smallholder farmers who combined crop cultivation, livestock rearing and fish culture as mixed livelihood strategies. Markets in small towns and urban centres provided demand for pond-produced fish, while local consumption had remained important for household nutrition.

Fig. 1. Districts of West Bengal

4. Pond types, design and construction

4.1 Pond types

Rural ponds had been classified based on origin and function:

- **Homestead ponds:** Small ponds (0.05–0.5 ha) adjacent to houses used primarily for household fish production, domestic needs and livestock watering.
- **Community ponds:** Medium-sized water bodies (0.5–2 ha) that served several households for communal purposes, sometimes managed by local panchayats or user groups.

- **Seasonal/Beel ponds:** Low-lying wetlands and seasonal depressions that filled during monsoon and were used for seasonal fish culture or rice-fish integration.
- **Irrigation-linked ponds:** Ponds constructed in association with field irrigation channels or embankments that served dual purposes of water storage and fish culture.

4.2 Design principles and construction practices

Ponds had been constructed following pragmatic local principles. Farmers selected sites with impermeable clay subsoil to minimize seepage, or they lined shallow ponds with locally available clay during construction. Ponds were typically kidney-shaped or rectangular depending on land parcelization and earth-moving convenience. Key structural features included:

- **Earthen embankments (bunds):** Bunds were compacted with local soil and reinforced by planting grasses (e.g., *Vetiver*, local grasses) to prevent erosion. Bund slopes were kept gentle to facilitate maintenance and access.
- **Inlets and outlets:** Simple bamboo or earthen inlets connected ponds to canals or drains, while sluice gates or bamboo weirs regulated water exchange. Outlets were designed to allow harvest and partial draining during management.
- **Depth profile:** Ponds were dug to varying depths; homestead ponds tended to be deeper (1.5–2.5 m) to provide year-round water during dry seasons, while seasonal ponds were shallower (0.5–1.5 m) and relied on monsoon. A desirable depth gradient with deeper central reaches and shallower fringes had been promoted for habitat heterogeneity.

Construction was often community-driven, with labour contributed by family members and neighbours; in some cases contractors with mechanical excavators were used where capital permitted. Ownership rights, embankment maintenance responsibilities and access regulations were governed by informal agreements or local institutions.

5. Species selection and stocking strategies

5.1 Common species cultured

Farmers had selected species based on growth performance, market preference, feed conversion, and resilience to local conditions. Commonly cultured species included:

- **Indian major carps:** Rohu (*Labeo rohita*), Catla (*Catla catla*), Mrigal (*Cirrhinus mrigala*). These species dominated mono- and polyculture practices due to high consumer preference and good growth.
- **Exotic carps:** Common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) were grown where growers sought robustness and specific niche markets (e.g., common carp for ponds with cooler microclimates).
- **Catfishes:** Walking catfish (*Clarias spp.*) and native catfishes were reared in some ponds for their high price and hardiness.
- **Small indigenous species (SIS):** Species like mola (*Amblypharyngodon mola*), punti and other small cyprinids strongly contributed to nutrient cycling and local diets.
- **Prawns:** In selected ponds with brackish influence or farmers with capital, freshwater prawns (*Macrobrachium rosenbergii*) were attempted.

5.2 Polyculture and stocking ratios

Polyculture, the practice of rearing multiple species together to exploit different food niches, had been widely adopted. A typical polyculture combination for semi-intensive homestead ponds was Catla:Rohu:Mrigal in ratios such as 1:2:1 or 1:3:2, sometimes supplemented with common carp or other species. Stocking densities varied with system intensity:

- **Extensive systems:** Low stocking densities (500–1,500 fingerlings per hectare) were practiced with minimal feeding and reliance on natural productivity.
- **Semi-intensive systems:** Moderate densities (5,000–20,000 fingerlings/ha depending on size and species mix) were common when supplementary feeding and fertilization were applied.
- **Intensive systems:** Higher densities (>20,000 fingerlings/ha) were rare among smallholders due to feed and management demands, but some progressive farmers experimented with higher stocking with commercial feeds.

Farmers had sourced fingerlings from local hatcheries, government nurseries and fellow farmers. Quality of seed and timely stocking were recognized as critical determinants of success; however, seed quality variability and limited access to certified fingerlings were persistent challenges.

6. Pond preparation and fertilization

6.1 Drying, liming and pond conditioning

Prior to stocking, farmers commonly drained ponds partially or fully during the dry season to facilitate cleaning. Drying helped in:

- Killing unwanted predatory fish and parasites.
- Allowing removal of excess organic sludge and debris.

Lime (calcium carbonate) application had been widely practiced to raise pH and alkalinity and to improve soil fertility. Farmers calculated lime doses empirically (e.g., 200–1,000 kg/ha depending on soil acidity and pond bottom composition). Liming had been followed by flooding and fertilization.

6.2 Fertilization practices

To stimulate natural food organisms (phytoplankton and zooplankton) that formed the base of nutrition, farmers applied organic and inorganic fertilizers. Common fertilization practices included:

- **Organic manures:** Cow dung, poultry droppings and composted plant residues were used at rates from 1,000 to 5,000 kg/ha per application. Organic matter increased nutrient levels and enhanced heterotrophic productivity.
- **Inorganic fertilizers:** Urea and single superphosphate (SSP) were sometimes applied to accelerate plankton bloom, with urea doses ranging from 50–200 kg/ha per application and SSP from 25–100 kg/ha. Farmers monitored water colour to assess plankton responses.
- **Biofertilizers and probiotics:** In more recent practices, where available, some farmers used formulated biofertilizers or probiotics to improve water quality and enhance natural productivity.

Timing of fertilization typically began a few weeks before stocking to build natural food stocks, and was continued periodically during the culture period based on water clarity and seasonality.

7. Water quality management

7.1 Key parameters and seasonal dynamics

Water quality had been a crucial determinant of pond productivity. Farmers monitored water quality indirectly by observation: water colour (greenish for good phytoplankton bloom), smell (foul odor signaled poor conditions), dissolved oxygen (DO) via fish behavior such as surface gasping, and transparency (measured by traditional Secchi-like visual checks). Key parameters included:

- **Temperature:** Seasonal temperature fluctuations influenced fish metabolism and growth; monsoon cooling and pre-monsoon heating affected oxygen solubility and plankton dynamics.
- **Dissolved oxygen (DO):** DO levels were highest in shallow, wind-exposed ponds during daylight and could fall at night due to plankton respiration and organic decomposition. Night-time DO dips were a recurrent risk, especially during early morning hours in dense plankton blooms.
- **pH and alkalinity:** Adequate alkalinity was necessary to buffer pH swings. Liming had been applied to maintain pH within acceptable ranges (approximately 6.5–8.5).
- **Nutrients (N and P):** Excess nutrients from fertilizers or runoff could lead to eutrophication and unstable conditions.
- **Ammonia and nitrite:** Accumulation resulted from intensive feeding and inadequate nitrification; these were seldom measured directly by farmers but were inferred from fish stress and mortalities.

7.2 Management techniques

Farmers adopted several strategies to maintain water quality:

- **Controlled fertilization and feeding:** Farmers adjusted feed input and fertilizer based on visual cues to avoid excessive organic loading.
- **Water exchange:** Partial water exchange during monsoon helped refresh ponds; however, infrastructure limitations often constrained the frequency and volume of exchanges.
- **Aeration:** Aerators were rare in smallholder ponds due to cost; instead, farmers leveraged wind exposure, shallow fringes and water circulation through inlet-outlet design. In some progressive farms, paddlewheel aerators or low-cost aerators powered by diesel engines were used.
- **Macrophyte management:** Excess growth of floating macrophytes (water hyacinth, duckweed) was controlled manually as they reduced dissolved oxygen and interfered with feeding and harvesting. Duckweed was occasionally used as feed.
- **Sediment management:** Periodic removal of sludge during drying or at harvest reduced organic accumulation and disease risk.

8. Feeding practices and feed resources

8.1 Natural food utilization vs. supplementary feeds

Traditional systems had relied heavily on natural food produced through fertilization. Supplementary feeding became more common as farmers aimed for higher yields. Feeding strategies ranged across a continuum:

- **Extensive feeding:** No supplementary feed; fish relied on naturally produced plankton and detritus.

- **Semi-intensive feeding:** Farmers provided household kitchen waste, rice bran, oil cake, and sometimes commercially produced pelleted feed.
- **Commercial feeds:** Finely milled pelleted or extruded feeds were used by some farmers who required higher growth rates, particularly for carp and prawn culture.

8.2 Locally available feed ingredients

Common feed materials included:

- **Rice bran:** Readily available and widely used as an energy source.
- **Mustard oil cake, linseed cake, and other oilseed cakes:** Used for protein supplementation.
- **Kitchen waste:** Vegetable residues, small animal leftovers and fish scraps were recycled into ponds in many homestead systems.
- **Green forage and aquatic plants:** Duckweed, water spinach and other macrophytes were used, especially for omnivorous species.
- **Pelleted feeds:** Where available, commercial feeds with known crude protein content were preferred for fingerlings and high-value species.

8.3 Feeding schedules and rates

Feeding schedules were often empirical and adjusted by farmers according to fish appetite, water temperature and growth observations. Feed rates generally ranged from 1–5% of estimated biomass per day in semi-intensive systems and varied with species and season. Farmers with limited feed resources tended to rely on split feeding and top-up of natural productivity rather than fixed formulated schedules.

9. Fish health, disease occurrence and management

9.1 Disease prevalence and triggers

Disease outbreaks had been episodic but serious threats. Common problems included parasitic infections (external parasites, protozoans), bacterial diseases (fin rot, bacterial gill disease), fungal infections (on eggs or injured tissues) and water-quality induced stress leading to mortality. Contributing factors included:

- Poor water quality (low DO, high ammonia).
- Overcrowding and high organic loading from overfeeding.
- Introduction of infected seed or wild fish during water exchange.
- Seasonal stressors, especially during pre-monsoon temperature spikes and monsoon-related fluctuations.

9.2 Diagnosis and treatment practices

Smallholder farmers primarily used experience-based signs for diagnosis — abnormal swimming, surface gasping, skin lesions, rapid mortalities — and applied traditional remedies or simple chemical treatments. Typical management approaches included:

- **Immediate partial draining and water exchange** to dilute pathogens and toxins.
- **Application of lime and salt** for mild cases to disinfect and reduce parasite loads.
- **Use of locally available antibiotics or antiseptics** in some cases, though access to proper veterinary guidance and risks of misuse were concerns.

- **Fallowing and pond drying** were used to break disease cycles.
- **Avoidance of stocking when disease risk was high**, and control of external introductions.

9.3 Extension and veterinary support

Formal aquatic veterinary services were limited in many rural areas, so farmers relied on local knowledge, feed suppliers, and occasional extension outreach. Strengthening diagnostic support and promoting biosecurity practices were repeatedly recognized as necessary for improving fish health outcomes.

10. Harvesting, processing and marketing

10.1 Harvesting methods

Harvesting ranged from partial harvests for immediate household consumption to complete harvests at culture termination. Common techniques included:

- **Seine netting or drain-and-catch:** Simple seine nets or lowering water levels to concentrate fish in shallow areas for capture.
- **Gill nets and cast nets:** Used for targeted harvests of specific species or sizes.
- **Trap harvests and fish traps:** Employed in communal or seasonal ponds.

Harvesting timing considered market demand, religious festivals, and household needs. Staggered partial harvesting helped manage pond stock and cash flow.

10.2 Post-harvest handling and value addition

Post-harvest handling was often minimal: fish were sold fresh in local markets or consumed at home. Preservation methods such as sun-drying, smoking and salting were used in households to increase shelf life and provide added value. Some farmers engaged in simple value-chain activities like gutting and cleaning for urban markets. Cold chain facilities were limited, constraining access to distant higher-value markets.

10.3 Market linkages and price dynamics

Market opportunities were shaped by proximity to urban centers, road access, and presence of intermediaries. Middlemen often dominated buying and logistics, which reduced returns to small producers. Price fluctuations were common, linked to seasonal supply, festivals and competition from other production systems (e.g., marine and inland commercial farms). Cooperative marketing and direct sales to local shops or consumers had emerged among some farmer groups as risk-reducing strategies.

11. Integration with agriculture and livestock

11.1 Rice-fish systems and seasonal integration

Rice-fish integration, practiced in seasonal wetlands and paddy-pond systems, had provided mutually beneficial outcomes. Fish contributed to pest control and nutrient recycling in paddy fields, while rice residues and field water provided habitat and feed. Farmers timed stocking to coincide with post-harvest or fallow periods.

11.2 Dairy-fish and manure recycling

Cow dung and livestock urine were major organic fertilizer sources for ponds, integrating livestock and aquaculture nutrient cycles. Conversely, pond sludge and spent water were used as fertilizer for adjacent crops, closing nutrient loops.

11.3 Multipurpose homestead ponds

Homestead ponds were multifunctional: they provided fish, domestic water, irrigation, and grazing for some livestock. Such multifunctionality increased resilience, diversified income and supported household nutrition security.

12. Gender, labour and knowledge systems

12.1 Gender roles in pond management

Gendered division of labour was evident: men typically managed construction, sourcing seed and negotiating sales, while women were heavily involved in routine tasks such as feeding, pond cleaning, harvesting small amounts for household consumption, processing (drying/smoking) and record-keeping in some households. Women's traditional ecological knowledge of pond productivity, feeding using kitchen waste, and fish processing were important but often undervalued in decision-making forums.

12.2 Labour arrangements and seasonal labour demand

Labour demand peaked during pond construction, stocking, fertilization, and harvest. Family labour supplemented by hired labour during peak periods had been a common arrangement. Youth migration to urban centres reduced available rural labour in some localities, impacting labour-intensive practices.

12.3 Knowledge transmission and extension

Knowledge transmission occurred through informal peer networks, local fishers, hatchery owners, and occasional extension programs run by agricultural departments and NGOs. Farmer field schools, demonstration ponds, and participatory training had been effective means where implemented.

13. Institutional support, extension and credit

13.1 Role of government and NGOs

Government fisheries departments had provided technical assistance, fingerling supply through nurseries, occasional subsidies for inputs, and training. NGOs had played roles in organizing farmer groups, facilitating access to markets, and piloting innovations such as low-cost aerators and improved feeds.

13.2 Access to credit and inputs

Access to formal credit for small-scale aquaculture had been limited, forcing farmers to rely on informal financiers, self-financing, or input-credit from local dealers. Subsidies for pond construction, pumps, and fingerlings had been available intermittently, but procedures and eligibility often excluded the poorest.

13.3 Collective action and cooperatives

Where present, farmer cooperatives and self-help groups had helped in bulk purchasing of inputs, collective marketing and securing better prices. Cooperative-run community nurseries had improved local seed availability and quality.

14. Environmental impacts and sustainability

14.1 Positive environmental roles

Ponds had provided ecosystem services including groundwater recharge, biodiversity habitat, carbon sequestration in sediments, and microclimate regulation. Integration of ponds in agricultural landscapes enhanced resource-use efficiency.

14.2 Negative environmental concerns

Conversely, some practices had negative local environmental impacts:

- **Eutrophication and oxygen depletion** from over-fertilization and overfeeding.
- **Pollution from antibiotics and chemicals** where used indiscriminately.
- **Loss of wetlands** when ponds were converted to non-aquatic uses or when small wetlands were filled for agriculture or development.
- **Spread of invasive aquatic weeds** such as water hyacinth, which altered pond ecology.

14.3 Pathways for sustainable management

Sustainable pond management emphasized balanced fertilization, integrated pest management, adoption of biosecurity measures, promotion of perennial vegetative buffers around ponds to reduce runoff, and use of locally adapted feed strategies to reduce dependency on external inputs.

15. Constraints and challenges

15.1 Technical constraints

- **Seed quality and availability:** Inconsistent supply of healthy fingerlings limited stocking and growth potential.
- **Water scarcity and variability:** Seasonal water shortages and irregular monsoon patterns created risks for continuous culture.
- **Poor access to improved feeds:** High cost and limited availability of commercial feeds constrained intensification.
- **Limited disease diagnostic services:** Lack of aquatic veterinary support increased vulnerability to disease outbreaks.

15.2 Economic and market constraints

- **Fluctuating market prices** and dominance of middlemen reduced profitability.
- **Limited cold chain and processing infrastructure** restricted access to premium markets.
- **High upfront costs** for pond renovation, aeration equipment and quality seed deterred investment.

15.3 Social and institutional constraints

- **Land tenure insecurity** for community and marginal farmers discouraged long-term pond investment.
- **Gender inequities** limited women’s access to credit, training and decision-making.
- **Fragmented extension services** and lack of coordinated policy support hindered knowledge diffusion.

16. Innovations and local adaptations

Despite constraints, farmers had developed several pragmatic innovations:

- **Use of locally produced feeds** combining rice bran, oilcakes and green forages to reduce feed costs.
- **Polyculture designs** tailored to available resources and market demand, optimizing size-class diversification for staggered harvests.

- **Low-cost aeration solutions** such as wind-driven paddles or solar pumps in some experimental setups.
- **Community-based seed production** where groups set up simple nurseries to improve seed availability and reduce costs.
- **Integration with duck rearing and piggery** to enhance nutrient recycling, where biosecurity risks were managed.

These adaptations illustrated farmers' resourcefulness and provided models for scaling appropriate technologies.

17. Recommendations for sustainable intensification

Building on observed practices and constraints, the following recommendations were advanced for improving sustainability and livelihoods:

17.1 Improve seed systems

- Promote certified hatcheries and community nurseries with quality assurance and training in broodstock management.
- Facilitate access to disease-free seed and encourage synchronized stocking to reduce disease transfer.

17.2 Strengthen feed and nutrition strategies

- Support development of locally produced high-protein feeds and training on balanced ration formulation.
- Encourage use of nutrient-rich by-products (e.g., oilseed cakes) and green forages with proven nutritional value.

17.3 Enhance water and pond management

- Promote practical water-saving practices (e.g., lining, improved inlets/outlets) and micro-irrigation integration.
- Introduce low-cost aeration technologies and train farmers on timing and dosage of fertilizers to avoid oxygen depletion.

17.4 Disease management and biosecurity

- Develop accessible aquatic veterinary services and rapid diagnostic networks.
- Train farmers in basic biosecurity: quarantine of new seed, avoid mixing wild-caught seed, and pond fallowing practices.

17.5 Market access and value addition

- Facilitate farmer cooperatives and collective marketing to reduce middleman dependence and improve bargaining power.
- Invest in small-scale processing (smoking, drying) and local cold storage to reduce post-harvest losses and access urban markets.

17.6 Gender-sensitive interventions and capacity building

- Design training and credit programs that targeted women explicitly and recognized their roles in pond management.

- Support community platforms for knowledge sharing, demonstration ponds and participatory technology evaluation.

17.7 Policy and institutional support

- Simplify access to subsidized inputs and credit for smallholder aquaculture.
- Implement zoning and wetland conservation measures to protect critical aquatic habitats and regulate conversion.

18. Case examples

18.1 Homestead intensification by a progressive farmer

A homestead pond owner near a small town Guptipara of Hooghly district had transitioned from extensive culture to a semi-intensive polyculture. She stocked a mixed carp combination, applied composted cow dung and urea strategically to build planktonic food, and supplemented with rice bran and oilcake. She practiced partial harvests timed with festivals and school fees, used pond sludge for kitchen gardening, and sold surplus fish directly in the town market. Her household nutrition improved and cash income supported children's education.

18.2 Community nursery initiative

In a cluster of villages, a group of farmers formed a cooperative to establish a fingerling nursery in Howrah district. By pooling resources, they produced quality seed for local members, reduced costs, and improved survival rates. The cooperative negotiated better prices for bulk feed and organized training sessions, demonstrating how collective action addressed seed and input constraints.

18.3 Rice-fish integration in seasonal wetlands

A village in Purba Midnapur district with extensive seasonal beels practiced rice-fish integration, stocking small indigenous fishes during monsoon and juvenile carps in post-monsoon months. Fish contributed to control of rice pests and provided additional protein for households. Seasonal income smoothing reduced vulnerability to crop failure.

19. Discussion

Pond-based aquaculture in South Bengal reflected many patterns documented for smallholder pond systems globally, while also showing region-specific features driven by cultural preferences, hydrology and institutional context. At a broad level, the global review of aquaculture's expansion and diversification highlighted that small-scale pond culture remained a critical source of local food and livelihoods even as commercial aquaculture expanded; this global perspective aligned closely with the South Bengal situation where homestead and community ponds continued to supply household nutrition and cash income (Naylor et al., 2021).

One of the clearest parallels between South Bengal and other South Asian systems was the long-standing prominence of carp polyculture and rice–fish integration. Studies from Bangladesh and regional reviews found rice–fish systems and carp polyculture to be efficient smallholder technologies that enhanced production per unit area and provided risk-smoothing benefits; these approaches mirrored farmers' widespread polyculture choices (Catla, Rohu, Mrigal, plus exotic carps) and seasonal rice–fish practices in South Bengal (Dey et al., 2013; Islam et al., 2015). The literature emphasized that polyculture exploited complementary trophic niches to increase total yield without proportionate increases in external inputs — a key reason why smallholders favoured these systems (Dey et al., 2013; Islam et al., 2015).

National-level Indian studies corroborated the dominance of Indian Major Carps in West Bengal ponds and described similar farmer-managed practices (fertilization with cow dung and urea, rice bran/oilcake feeding, pond drying and liming) that were observed in South Bengal field descriptions (Beg et al., 2024). These Indian studies also reported the same seed-quality constraints, seasonal water variability and market-access bottlenecks that limited intensification for smallholders — issues that the West Bengal state reports and local research had repeatedly flagged (Beg et al., 2024).

International comparative literature added nuance to how integration and gender functioned in smallholder aquaculture. Research from Bangladesh and other South Asian contexts found that rice–fish and homestead pond systems often delivered important nutrition gains and women's income opportunities, but these benefits depended on enabling interventions (training, seed access, organized marketing) (Dey et al., 2013; Freed et al., 2020). Similarly, case studies in West Bengal documented women’s significant involvement in feeding, processing and small-scale marketing, but also persistent barriers to credit and formal recognition — echoing regional findings that gender-inclusive programming increased uptake and benefits (Freed et al., 2020; regional NGO reports).

A recurring theme across national and international studies was the centrality of seed systems and the quality of hatchery-produced fry. Comparative analyses from India and East Africa showed that unreliable seed supply — in quality, timing and species composition — consistently depressed farm-level productivity and raised disease risk, a point reinforced by local West Bengal research (Byabasaija et al., 2025; FAO reviews). This literature suggested that strengthening community nurseries and certification systems could substantially raise smallholder yields and reduce vulnerability to pathogens (FAO; Byabasaija et al., 2025).

Water quality and disease management also emerged as cross-cutting constraints. Global and regional reviews highlighted that smallholder ponds often lacked routine water-quality monitoring and formal veterinary support, which increased the frequency and severity of mortality events; local West Bengal reports reflected the same pattern of empiric, experience-driven management and occasional misuse of antibiotics or chemicals (Naylor et al., 2021; research from West Bengal). The international literature underlined that interventions combining low-cost monitoring tools, basic training in biosecurity, and community-level rapid-diagnostic links were among the most cost-effective measures to reduce losses in smallholder systems.

Studies focusing on feed and feed-resource use provided another point of comparison. In many developing-country contexts researchers found that reliance on by-products (rice bran, oilseed cakes, kitchen waste) was widespread and often cost-effective, but limited the growth potential of ponds compared to farms using formulated pelleted feeds (Beg et al., 2024; FAO analyses). West Bengal smallholders showed the same trade-off: low-cost local feeds supported low-to-moderate yields and high resilience, but constrained rapid intensification without improved, locally-producible feed formulations. Several national trials in India and regionally reported promising results for mixed-formula feeds based on locally available ingredients — a direction that matches farmer innovation documented in South Bengal.

Market structures and value chains were another shared challenge. Comparative studies from South Asia and East Africa showed that middlemen-dominated value chains, poor cold-store infrastructure, and price seasonality depressed producer margins and reduced incentives for investments in improved culture (Byabasaija et al., 2025; East African reviews). West Bengal research described similar market frictions: smallholders often sold in local wet markets or through intermediaries, with limited access to urban value chains that could pay premiums for size-graded, fresh or processed products. Collective marketing initiatives and cooperatives in both national and international examples showed some success in improving farmer returns, indicating a policy-relevant pathway for South Bengal.

Environmental sustainability research provided mixed lessons. Global reviews emphasized aquaculture's potential for both positive ecosystem services (micro-habitat provision, nutrient recycling) and negative impacts (eutrophication, chemical pollution) depending on management intensity (Naylor et al., 2021). Local West Bengal studies likewise documented this duality: ponds supported biodiversity and integrated nutrient cycles with agriculture when managed at low-to-moderate intensity, but intensified or poorly managed systems risked oxygen depletion, weed proliferation and chemical residues. This convergence suggests that regionally adapted best-practice guidelines (balanced fertilization, feed management, vegetated buffers) developed elsewhere were applicable to South Bengal with local calibration.

Finally, the literature emphasized that scaling benefits from pond aquaculture required bundling technical, institutional and market interventions. Multi-component programs in South Asia that combined seed-hatchery strengthening, farmer training, gender-inclusive extension, and collective marketing delivered stronger livelihood outcomes than single-intervention projects (Dey et al., 2013; FAO case studies). West Bengal's policy programs (e.g., PMMSY-related initiatives) echoed this integrated approach, and recent pilot projects showed promise where they concentrated inputs, technical support and market access in targeted clusters.

In sum, national and international research largely corroborated the empirical picture from South Bengal: pond aquaculture was a resilient, multifunctional element of smallholder livelihoods with clear potential to scale benefits, but technical constraints (seed, feed, disease), market weaknesses, gendered access issues, and environmental risks had to be addressed through integrated, locally contextualized interventions that blended improved technologies with collective action and enabling policy.

20. Monitoring and research needs

To further improve pond aquaculture outcomes in South Bengal, targeted research and monitoring priorities were identified:

- **Water quality baseline studies** across seasons to guide adaptive fertilization and feeding regimes.
- **Feed trials** using locally available ingredients to develop cost-effective, nutritionally balanced formulations for smallholder contexts.
- **Disease epidemiology** research to characterize prevalent pathogens, vectors and management options suitable for low-resource systems.
- **Socio-economic studies** on gendered roles, market chains, price formation and the impact of aquaculture on household nutrition and poverty reduction.
- **Climate resilience research** to evaluate pond designs and culture calendars that cope with changing monsoon patterns and extreme events.

Participatory on-farm research with farmers as co-researchers had the highest potential for uptake.

21. Conclusion

Pond aquaculture in rural South Bengal had represented a resilient, multifaceted livelihood strategy that combined tradition with incremental innovation. Homestead and community ponds had provided nutrition, income and ecosystem services while supporting integration with agriculture and livestock. Farmers had developed locally adapted practices — polyculture, judicious fertilization, use of household feed resources and multi-use pond designs — that balanced productivity with limited resources. Yet, challenges remained: seed quality, disease management, access to quality feed, market volatility and environmental sustainability constrained the sector's growth.

Sustainable intensification required coordinated action: strengthening seed systems, promoting affordable and nutritious feeds, enhancing water and disease management, investing in market infrastructure and cold chains, and instituting gender-sensitive extension and finance mechanisms. Community-based approaches and farmer cooperatives had shown promise in overcoming input and market constraints. Research and extension had to be locally grounded, seasonal in orientation, and oriented to smallholder realities.

With appropriate policy support and participatory innovation, pond aquaculture in South Bengal had the potential to continue improving household livelihoods, enhancing food security and contributing to rural development while maintaining ecological integrity.

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