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Sustainable Aquaculture Practices in India: Challenges, Innovations, and Future Prospects

*Aditi Banasure
Masters in Fisheries Engineering and Technology, College of Fisheries, Shirgaon, Ratnagiri, Maharashtra, India
*Corresponding Author's email: aditibanasure05@gmail.com

Aquaculture has emerged as one of the fastest-growing food production sectors worldwide and plays a crucial role in ensuring food security, nutritional security, employment generation, and rural economic development. India is the world's second-largest producer of fish, with aquaculture contributing more than 70% of the country's total fish production. However, rapid expansion has resulted in challenges such as water pollution, disease outbreaks, excessive feed usage, biodiversity loss, and climate-related risks. Sustainable aquaculture aims to balance economic profitability with environmental conservation and social well-being. This review discusses the current status of Indian aquaculture, sustainable farming practices, emerging technologies, government initiatives, major challenges, and future prospects for environmentally responsible aquaculture.

Keywords: Sustainable aquaculture, Biofloc, RAS, India, Fisheries, Climate-smart aquaculture, Aquaponics, Blue Economy

Introduction

Aquaculture refers to the farming of fish, crustaceans, molluscs, aquatic plants, and other aquatic organisms under controlled conditions. India possesses abundant freshwater resources numerous reservoirs, ponds, rivers, and estuaries, making it one of the world's leading aquaculture nations. The sector contributes significantly to national food security, export earnings, employment, and rural livelihoods. Sustainable aquaculture has become increasingly important because conventional intensive farming often leads to environmental degradation, excessive nutrient loading, disease outbreaks, and inefficient resource utilization. The Food and Agriculture Organization (FAO) emphasizes sustainable aquaculture as a key component of global food systems, and in 2025 released the first international Guidelines for Sustainable Aquaculture to support environmentally responsible growth (FAO, 2025).

Current Status of Aquaculture in India

India ranks second globally in fish production and is among the leading producers of farmed shrimp. Freshwater aquaculture is dominated by Indian major carps (Catla, Rohu, and Mrigal), while Pacific white shrimp (*Litopenaeus vannamei*) dominates coastal aquaculture.
Major aquaculture-producing states include: Andhra Pradesh, West Bengal, Odisha, Gujarat, Tamil Nadu, Kerala, Karnataka, Maharashtra. The fisheries sector contributes substantially to agricultural GDP while supporting millions of livelihoods through farming, processing, transportation, and exports (FAO, 2024).

Principles of Sustainable Aquaculture

Sustainable aquaculture is based on three major pillars:

- Environmental sustainability
- Economic viability

- Social responsibility

Its objectives include:

- Efficient utilization of water resources
- Reduction of pollution
- Conservation of biodiversity
- Improved animal welfare
- Climate resilience
- Enhanced farmer income
- Long-term productivity

Sustainable Aquaculture Practices in India

Biofloc Technology (BFT)

Biofloc technology is an eco-friendly production system where beneficial microorganisms convert toxic nitrogenous wastes into microbial protein.

Advantages

- Reduces water exchange
- Improves feed conversion ratio
- Enhances fish immunity
- Lowers environmental pollution
- Suitable for water-scarce regions

Challenges include high aeration requirements, electricity costs, and the need for technical expertise. Biofloc has been widely promoted under government capacity-building programmes.

Recirculating Aquaculture Systems (RAS)

RAS continuously filters and reuses water through mechanical and biological filtration.

Benefits

- Saves up to 90–99% of water
- High stocking density
- Better disease control
- Suitable for urban aquaculture
- Minimal environmental discharge

Its limitations include high capital investment and energy consumption. Recent life-cycle assessments indicate that integrating renewable energy can significantly improve the sustainability of RAS (Mohamed et. al., 2026).

Integrated Fish Farming

Integrated farming combines aquaculture with agriculture and livestock.

Examples include:

- Fish-cum-duck farming
- Fish-cum-poultry farming
- Fish-cum-rice farming

Benefits:

- Efficient nutrient recycling
- Reduced production costs
- Increased farm income
- Improved resource utilization

Aquaponics

Aquaponics integrates fish culture with hydroponic vegetable production.

Fish waste provides nutrients for plants, while plants naturally purify the water before it returns to the fish tanks.

Advantages:

- Water-efficient production
- Chemical-free vegetable cultivation
- Reduced fertilizer requirement
- Suitable for urban farming

Recent studies highlight aquaponics as a promising sustainable "aqua-agriculture" approach in India (Bhanja et. al., 2024).

Climate-Smart Aquaculture

Climate-smart aquaculture focuses on:

- Increasing productivity
- Enhancing climate resilience
- Reducing greenhouse gas emissions

Key practices include:

- Efficient water management
- Weather-based farm planning
- Climate-resilient fish species
- Renewable energy adoption
- Early disease warning systems

Indian research identifies these approaches as increasingly important for inland aquaculture under changing climatic conditions (Tanuja, 2025).

Sustainable Feed Management

Feed accounts for the largest share of aquaculture production costs and environmental impacts.

Sustainable feed strategies include:

- Plant-based protein ingredients
- Insect meal
- Algal protein
- Precision feeding
- Feeding based on fish appetite
- Feed quality improvement

Research consistently identifies feed production as the primary environmental hotspot in aquaculture systems, making sustainable feed formulation a key priority (Giri, 2024).

Water Quality Management

Maintaining optimum water quality reduces disease incidence and improves growth.

Important parameters include:

- Dissolved oxygen
- Temperature
- pH
- Ammonia
- Nitrite
- Alkalinity

IoT-based sensors and automated monitoring systems are increasingly being adopted for precision aquaculture.

Responsible Disease Management

Sustainable disease control involves:

- Biosecurity measures
- Healthy seed selection
- Vaccination (where applicable)
- Probiotic application
- Reduced antibiotic use
- Regular health monitoring

Government Initiatives Supporting Sustainable Aquaculture

Major initiatives include:

- Pradhan Mantri Matsya Sampada Yojana (PMMSY)
- Blue Revolution Scheme
- Fisheries and Aquaculture Infrastructure Development Fund (FIDF)
- National Fisheries Development Board (NFDB)
- ICAR-Central Institute of Freshwater Aquaculture (CIFA)
- ICAR-Central Institute of Brackishwater Aquaculture (CIBA)
- ICAR-Central Marine Fisheries Research Institute (CMFRI)

These programmes promote scientific aquaculture, infrastructure development, climate resilience, and farmer training.

Emerging Technologies

Recent innovations include:

- Artificial Intelligence (AI)
- Internet of Things (IoT)
- Smart feeding systems
- Remote water quality monitoring
- GIS mapping
- Drone surveillance
- Machine learning for disease detection
- Blockchain for seafood traceability

Challenges to Sustainable Aquaculture

Major constraints include:

- Water scarcity
- Disease outbreaks
- Climate change
- High feed costs
- Habitat degradation
- Antibiotic misuse
- Limited technical knowledge
- Financial constraints for small-scale farmers

Future Prospects

Future growth of Indian aquaculture depends on:

- Adoption of precision aquaculture
- Expansion of biofloc and RAS

- Renewable energy integration
- Sustainable feed development
- Digital extension services
- Stronger farmer training
- Circular economy approaches
- Climate-resilient production systems

Conclusion

Sustainable aquaculture is essential for ensuring long-term food security, environmental conservation, and economic prosperity in India. Scientific management practices such as biofloc technology, recirculating aquaculture systems, aquaponics, integrated farming, climate-smart aquaculture, and precision farming provide practical solutions for increasing productivity while minimizing ecological impacts. Continued investment in research, technological innovation, policy support, and farmer capacity building will enable India to strengthen its position as a global leader in sustainable aquaculture.

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