



Wastewater Management in Aquaculture: Sustainable Approaches for Water Reuse, Pollution Reduction and Resource Recovery

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Aquaculture is one of the fastest-growing food-production sectors, but intensive farming can generate wastewater containing suspended solids, uneaten feed, faecal matter, nutrients and organic compounds. If discharged without adequate treatment, aquaculture effluent can contribute to eutrophication, oxygen depletion and deterioration of receiving water bodies. Effective wastewater management is therefore essential for environmentally responsible and economically sustainable aquaculture. Modern approaches include sedimentation, mechanical filtration, biofiltration, constructed wetlands, probiotics, biofloc technology, recirculating aquaculture systems, integrated multitrophic aquaculture and nutrient recovery. These approaches can reduce water consumption while converting waste nutrients into useful biomass. This article reviews major sources of aquaculture wastewater, its characteristics, environmental impacts and practical treatment and reuse strategies.

Keywords: Aquaculture wastewater, effluent management, biofilter, constructed wetland, RAS, biofloc, nutrient recovery, water reuse

Introduction

Aquaculture has become an important source of aquatic food, employment and rural livelihood. Increasing intensification has improved production efficiency but has also increased the quantity of waste generated within farming systems. The major waste components include uneaten feed, faeces, metabolic excretion products, dead plankton and suspended solids. Aquaculture wastewater commonly contains organic matter, nitrogen, phosphorus and suspended solids. The quantity and composition vary with species, stocking density, feeding rate, culture system and water-exchange practices (Cripps and Bergheim, 2000). The objective of wastewater management should not simply be disposal. Instead, wastewater should be treated as a potential resource containing nutrients and organic matter that can be recovered and reused.

Major Sources of Wastewater

The principal sources include:

- pond drainage;
- tank and raceway discharge;
- hatchery wastewater;
- RAS backwash water;
- sludge from culture tanks;
- harvesting and grading water;
- processing and cleaning water;
- water discharged during disease-treatment operations.

Among these, intensive systems may generate concentrated effluents, while extensive ponds may produce larger volumes of relatively dilute wastewater.

Major Pollutants in Aquaculture Effluent

Pollutant	Major source	Potential effect
Suspended solids	Faeces, uneaten feed	Turbidity and sedimentation
Organic matter	Feed and faeces	Oxygen depletion
Ammonia	Fish excretion and decomposition	Toxicity to aquatic organisms
Nitrite	Nitrification processes	Toxicity at elevated concentrations
Nitrate	Nitrification	Eutrophication at high loading
Phosphorus	Feed and faeces	Algal blooms/eutrophication
Pathogens	Fish and contaminated water	Disease transmission
Chemicals	Therapeutic and cleaning agents	Ecological effects

Effluent quality should therefore be monitored according to the species, farming system and local regulatory requirements.

Environmental Impacts

Eutrophication

Nitrogen and phosphorus discharged from aquaculture facilities can stimulate excessive algal growth in receiving water bodies. Subsequent decomposition of organic matter can reduce dissolved oxygen and affect aquatic organisms.

Oxygen depletion

Organic matter in effluent increases biochemical oxygen demand. Microbial decomposition consumes dissolved oxygen, particularly when large quantities of untreated effluent enter small water bodies.

Suspended solids

Fine particles can increase turbidity and settle on the bottom of receiving ecosystems. Excessive sedimentation may affect benthic organisms and habitat quality.

Ammonia and nitrite

Ammonia is a major metabolic waste product in fish culture. Under unsuitable water-quality conditions, the unionised form of ammonia can become toxic. Nitrite is another important nitrogen compound that requires control in intensive culture systems.

Wastewater Treatment Approaches

A successful wastewater management system generally combines several treatment stages.

Primary treatment: Solid removal

The first step should normally be removal of large and settleable particles.

Common methods include:

- sedimentation tanks;
- settling ponds;
- sludge collectors;
- screens;
- drum filters;
- mechanical filters.

Removing solids early reduces the organic load entering biological treatment units.

Biological treatment

Biological treatment uses microorganisms to convert toxic or undesirable compounds into less harmful forms.

Biofilters containing nitrifying bacteria convert ammonia to nitrite and subsequently nitrate. This process is fundamental to recirculating aquaculture systems (Martins et al., 2010).

Constructed wetlands

Constructed wetlands combine sedimentation, filtration, microbial activity and plant uptake. Plants such as *Phragmites*, *Typha* and other suitable wetland species can contribute to nutrient removal.

Constructed wetlands can be particularly useful for small and medium-scale farms because they may require relatively simple infrastructure.

Disinfection

Where necessary, treated water can undergo disinfection using ultraviolet radiation, ozone or other approved methods. The choice depends on the production system and intended water reuse.

Disinfection should be implemented carefully because excessive treatment can also affect beneficial microorganisms in systems where biological activity is required.

Recirculating Aquaculture Systems

Recirculating aquaculture systems (RAS) are designed to treat and reuse culture water. A typical RAS includes:

Culture tank → solids removal → biofilter → degassing/aeration → disinfection (if required) → culture tank

RAS can substantially reduce water exchange compared with conventional flow-through systems. However, RAS requires investment in pumps, filtration, aeration, monitoring and backup systems. Effective management of solids and biofilter performance is essential (Martins et al., 2010).

Biofloc Technology

Biofloc technology provides an alternative approach to nutrient management. Carbon supplementation encourages microbial assimilation of inorganic nitrogen into microbial biomass. The resulting bioflocs can be consumed by cultured organisms and contribute to nutrient recycling. Biofloc systems can reduce water exchange and improve nutrient utilisation, although careful management of carbon, dissolved oxygen, alkalinity and suspended solids is required (Avnimelech, 2015).

Integrated Aquaculture and Nutrient Recovery

Instead of treating wastewater only for disposal, nutrients can be recovered through integrated production systems.

Examples include:

Fish culture → nutrient-rich effluent → plant production → treated water → fish culture

Aquaponics combines aquaculture with hydroponic plant production, allowing plants and microorganisms to utilise nutrients originating from fish waste.

Similarly, integrated multitrophic aquaculture (IMTA) combines species occupying different trophic and ecological functions so that waste from one component can become a resource for another (Chopin et al., 2012).

Aquatic Plants for Wastewater Treatment

Aquatic plants can absorb dissolved nutrients and provide additional biological treatment. Depending on local conditions, species such as duckweed, water spinach and suitable wetland plants can be evaluated for nutrient recovery. However, harvested plant biomass should be managed carefully. If nutrient-rich biomass is allowed to decompose within the treatment system, nutrients can be released back into the water.

Sludge Management

Wastewater management should include sludge management because solids removed from culture water contain considerable organic matter and nutrients.

Possible approaches include:

- settling and dewatering;
- composting;
- anaerobic digestion;
- agricultural use after appropriate treatment;
- nutrient recovery.

Sludge should not be directly discharged into natural water bodies.

Water Reuse

Treated aquaculture wastewater can potentially be reused depending on water quality and the production system. Reuse options include:

- rearing water after adequate treatment;
- pond make-up water;
- irrigation;
- aquaponic plant production;
- cleaning applications where appropriate.

Before reuse in fish culture, parameters such as dissolved oxygen, ammonia, nitrite, nitrate, pH, alkalinity, suspended solids and microbial quality should be evaluated.

Best Management Practices

Effluent generation can be reduced at the source through better farm management.

Feed management

Feed is one of the largest sources of nutrients entering aquaculture systems. Overfeeding increases uneaten feed and waste production. Feeding according to biomass, temperature, fish behaviour and feeding response can reduce nutrient losses.

Stocking density

Excessive stocking density can increase metabolic waste and organic loading. Appropriate stocking density improves water quality and reduces treatment requirements.

Regular removal of solids

Prompt removal of faeces and uneaten feed prevents their decomposition within culture water.

Water-quality monitoring

Regular monitoring of pH, dissolved oxygen, temperature, ammonia, nitrite and other relevant parameters allows corrective action before water quality deteriorates.

Challenges

Despite technological advances, wastewater management faces several challenges:

- high initial investment for advanced treatment systems;
- electricity requirements for pumping and aeration;
- technical expertise requirements;
- variable effluent composition;
- pathogen and biosafety concerns;
- inadequate treatment infrastructure in small farms;
- lack of systematic monitoring;
- inappropriate disposal of sludge.

Therefore, treatment technology should be selected according to farm size, species, production intensity, available land, water availability and economic capacity.

Conclusion

Effective wastewater management is essential for sustainable aquaculture. Untreated effluent containing suspended solids, organic matter, nitrogen and phosphorus can negatively affect receiving ecosystems. However, appropriate management can transform wastewater from an environmental liability into a resource. A combination of solids removal, biological filtration, constructed wetlands, biofloc technology, RAS, aquaponics and integrated production systems can reduce pollution and water consumption. Improved feed management and regular water-quality monitoring are equally important. The future of sustainable aquaculture should therefore move from a “use and discharge” model towards a “treat, reuse and recover” model.

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