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WATER QUALITY IN AGRICULTURE: **Risks and risk mitigation**

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Chapter 6

Water quality and aquaculture

Philip Amoah and Pay Drechsel

Water quality is very important in fish farming as poor-quality water can affect the health and growth of the fish. On the other hand, fish farming can also significantly affect water quality. Both components will be addressed in this section.

The most effective and reliable means to minimize possible contamination of fish is to harvest from areas with good water quality. In terms of best practice, authorities should therefore encourage, promote and strive to maintain excellence in regard to water quality in fish production areas (Lees, Younger & Dore, 2010). Unfortunately, worldwide degradation of freshwater and marine environments caused by discharges from human settlements and agricultural activities has led to a shortage of pristine environments suitable for aquaculture, highlighting the need for guidelines such as these.

Water quality plays a particularly important role in freshwater aquaculture with the ability to both support and undermine the production of fish and aquatic crops. For farmers, low water quality is a condition to avoid or manage where there is no alternative, or may also constitute a choice. For example, farmers might consciously seek nutrient-rich water that can feed fish and save on operational expenditure. In most situations, however, proximity to urban markets makes peri-urban areas both hotspots for aquaculture initiatives and areas prone to pollution and competition for land and safe water.

Particular support is needed for those enterprises where wastewater is affecting lakes, lagoons, deltas or other wetlands used for farming (Table 6.1). In such natural but highly polluted systems, farmers might target areas closer to the wastewater inflow given the strong positive correlation between organic load, savings on fish feed and high fish growth (Mukherjee & Dutta, 2016).

The most conscious selection of wastewater for farming fish or aquatic plants is the cultivation of fish or crops in waste stabilization ponds (WSPs) of wastewater treatment systems, where farming usually takes place in the last of a system of interconnected treatment ponds. These "maturation" ponds contain the most "treated" water (Table 6.2).

The fish species commonly cultivated in aquaculture systems with low water quality consist of different varieties of carp, catfish and tilapia. The main aquatic plants are lotus, water mimosa, water cress and water spinach, which are used, for example, as traditional medicine or as vegetables for human consumption, or as feed for fish or poultry (in the case of duckweed). Through their ability to transform nutrients into biomass, aquatic macrophytes can contribute significantly to wastewater treatment (Edwards, 1990; Pescod, 1992; WHO, 2006).

Table 6.1. Common water quality affected systems used for fish or aquatic plant production

Fish farm location	Brief description of the aquaculture system	Source
Lakes in urban vicinity serving as natural treatment systems (mostly unplanned)	Water bodies such as Beung Cheung Ek Lake near Phnom Penh, Cambodia, receive largely untreated wastewater from the city. The lake employs biological treatment of wastewater, recapturing nitrogen (N) and phosphorus (P) to produce aquatic vegetables such as morning glory (water spinach) for human and animal consumption.	Kuong, Little & Leschen (2006) Leschen (2018)
Wastewater drains and irrigation channels, paddy fields and farmer-made ponds	Treated and untreated wastewater are directed through a network of channels. Three systems have been observed in Hanoi: (i) fish culture alone, (ii) fish-rice rotations, and (iii) fish-rice-vegetable rotations. In Ho Chi Minh City, a network of smaller, less-defined wastewater channels support the growth of different aquatic plants for human or animal consumption, as well as ornamental fish and fish for consumption.	Minh Phan & Van de Pauw (2005); Hung and Huy (2005); Tuan & Trac (1990)
Wastewater-fed wetlands which function as treatment systems	Natural wastewater-fed ponds and lagoons receive diluted or raw wastewater from the city for treatment. Wetland ponds are usually large and can be 40–50 ha in size. The 12 500 ha of wastewater-fed wetlands in Calcutta, India, are considered the world's largest operational system for the culture of fish in ponds or cages.	Leschen (2018) Leschen, Little & Bunting (2005) Mukherjee & Dutta (2016)
River deltas	Deltas encompass a large variety of aquaculture, including coastal fisheries, brackish water aquaculture (e.g. shrimp farms) and riverside prawn collection. Other systems combine aquaculture with rice production and/or animal husbandry. Water quality is affected by upstream pollution, saline water intrusion and agricultural intensification (including impacts from pond effluent). Examples include the Nile, Mekong, Indus and Ganges deltas.	Oczkowski & Nixon (2008) Nguyen (2017) SourceTrace (2018)

Source: Authors' own elaboration.

Table 6.2. WSP-based fish and fish feed production systems

Production target	Brief description	Source
Fish farming	Fish cultivation in the maturation ponds of the WSP system	Amoah, Gebrezgabher & Drechsel (2021)
Fish farming and irrigation	Fish production within the [facultative and] maturation ponds; treated effluent used for crop irrigation	Kumar *et al.* (2015)
Broodstock production for external fish (and crop farming)	Broodstock cultivation in the maturation ponds of the system; while fingerlings and fish for sale are grown in clean water tanks. Crops are cultivated with wastewater from the fish tanks.	Amoah, Gebrezgabher & Drechsel (2021)
Aquatic plants to feed externally cultivated fish	Aquatic plants grown within the ponds, absorb nutrients, and are either sold or used internally (e.g. as fish feed for fish grown in separate (clean water) ponds or ponds using treated wastewater).	Drechsel *et al.* (2018); Amoah, Gebrezgabher & Drechsel (2021); FAO (1998)

Source: Authors' own elaboration.

6.1. Managing water quality

The key objectives of water quality management are to provide fish with the best possible living conditions, consumers with a safe product and the environment with a well-treated final effluent. All three targets are interlinked as water quality affects feed efficiency, growth rates, fish health and survival, and requires a well-managed integrated system (Kumar & Sierp, 2003; Mara, 2004; Isyagi *et al.*, 2009).

In successful and high-yielding aquaculture systems, farmers work to achieve the maximum standing stock of fish (pond carrying capacity) through balancing an optimal supply of food with an optimal level of oxygen, while minimizing the build-up of toxic metabolic products. Fish mortality in a pond that receives raw or diluted wastewater can result from (i) depletion of oxygen due to an increase in organic load (feed and fish excreta); (ii) depletion of oxygen due to the respiratory demand of a high concentration of phytoplankton caused by an increase in inorganic nutrients; and (iii) a high ammonia concentration due to accumulation of waste (Pescod, 1992).

A wide range of yields have been reported from waste-fed aquaculture systems ranging from: 2–6 t/ha/yr in Indonesia to 2.7–9.3 t/ha/yr in China and 3.5–7.8 t/ha/yr in Taiwan. Management of fish ponds can have a significant effect on fish yields, but in practice the maximum attainable yield is 10–12 t/ha/yr even with energy-rich supplementary feed (Edwards, 1990; Pescod, 1992).

The key water quality parameters for pond production are temperature, oxygen, pH, alkalinity, hardness and certain nutrient levels. Ammonia, for example, can be directly toxic to fish (the fish's own excretion of ammonia is impaired) or support the growth of toxin-producing cyanobacteria (Isyagi *et al.*, 2009; WHO, 2006). Crucially, different species can have different water quality requirements, while the concentrations of many parameters vary with changes in temperature, salinity, hardness, pH and stocking density, among others. Dissolved oxygen (DO) is a common example of a factor that can vary significantly with temperature, species, age or life stage (eggs, larvae, adults) and life process (feeding, growth, reproduction). Several fish cultured in waste-fed ponds appear to be able to tolerate very low DO concentrations for at least short periods of time. African catfish, for example, have accessory organs that enable them to breathe atmospheric oxygen and thus better survive in water at low oxygen levels for short periods. However, this ability does not apply to juvenile catfish, which depend on dissolved oxygen in the water (Isyagi *et al.*, 2009). In other words, an oxygen deficit might not affect the survival of adult fish but would prevent its reproduction. Thus, before stocking fish in a treated wastewater pond, fingerlings should be raised in clean water to the required size (for catfish about 50 g) to achieve a survival rate of 80-90 percent (Isyagi *et al.*, 2009). Air-breathing catfish such as *Clarias batrachus* and *Pangasius bocourti* are followed in decreasing order of tolerance by tilapia, carps and trout. A wastewater fertilized aquaculture system might therefore occasionally require a stand-by mechanical oxygenation system for use during periods when DO would otherwise be very low (Pescod, 1992).

Table 6.3 presents the desirable water quality values recommended by various sources for fish farming. Fish can survive within a wide range, but certain values affect growth or reproduction. Tilapia, for example, can tolerate a pH from 3.7 to 10.5, but below pH 5, they become stressed and will not eat (WRC, 2010).

Table 6.3. Desirable water quality ranges for wastewater-fed aquaculture (warm water species)

Sources	Kaul *et al.* (2002) (India)	Isyagi *et al.* (2009) (Uganda)	PHILMINAQ (2008) (Philippines)	Asmah *et al.* (2016) (Ghana)	BC MOE (2019) (Canada)	DWAF (1996) (South Africa)
pH (comfort zone)	7.5–8.5	6.5–9.0	6.5–9.0	6.5–9.0	6.5–9.0	6.5–9.0
Temperature (°C)	26–33	26 32		22–38		28–30
Dissolved oxygen (DO) (mg/L)	3–10	>4	≥5	3.7–9.0	5–11	5–8
Alkalinity (mg/L) as $CaCO_3$		>20	>20–100	54–200	>20	20–100
Ammonia-nitrogen (mg/L)	<0.25	0.3		<0.5	0.1–1.2*	0–0.3
Dissolved reactive phosphate (mg/L)			0.05–0.1	<1.5		<0.1

* Depending on pH (pH 6.5: 1.2 mg/L; pH 9.0: 0.1 mg/L; for 200C)

Source: Authors' own elaboration.

When fish are cultivated in wastewater treatment systems, the twofold objective of optimizing water treatment and fish production can present a challenge. While a high organic loading will reduce DO and limit the number of fish species that can be cultivated, a low organic loading can result in a correspondingly low level of nutrients for growing phytoplankton – the main source of natural food in fish ponds, and therefore one which represents savings in fish feed (Kaul *et al.*, 2002). Mara (2004) provides design options for wastewater-fed fishponds based on the concept of "minimal treatment for maximal production of microbiologically safe fish".

Locally appropriate fish species can be selected based on their availability and the characteristics of the treated wastewater. African Catfish (*Clarias gariepinus*), for example, is very adaptive to environmental conditions, as found in WSPs, and can live in a wide range of pH and low levels of dissolved oxygen. Species like tilapia, carp, and prawn, on the other hand, would require artificial aeration, like reported from China, India and Viet Nam. Thus, water quality also depends on pond management. Mismanagement will hinder the success of treated wastewater aquaculture systems and can even lead to failure. Many water quality parameters fluctuate daily due to pond dynamics, which include local weather (temperature) conditions, the photosynthetic activities of aquatic plants and so on.

In view of the chemical risks for fish and the food chain, the general recommendation is that industrial effluents should be avoided, or at least be pre-treated within the industry, to remove chemicals likely to enter the same streams as municipal wastewater. Both courses of action are, however, seldom possible in many low-income countries. Thus, where water might contain industrial effluent with potentially toxic chemicals (Table 6.4), bioaccumulation is possible and its use in fish farming is discouraged. However, different chemicals present different levels of risk.

In WSPs, most heavy metals are precipitated under the anaerobic conditions in the first WSP or lose solubility under increasing pH in the maturation pond(s). Algae can accumulate various heavy metals, but fish raised in sewage-fed ponds have not been observed to accumulate high concentrations of possible toxic substances with the possible exception of mercury (Pescod, 1992). One reason is that fish are usually harvested young, and any possible bio-accumulation of toxic metals remains limited. Consequently, the risks from most heavy metals for human health from fish raised in sewage-fed waste stabilization ponds has been assessed as low (WHO, 2006), similar to consumption risks from pesticides or antibiotics even in high-input aquaculture (Murk, Rietjens & Bush, 2018).

Table 6.4. General acceptable levels of selected heavy metals for freshwater environments

Country	Freshwater (µg/L)			
	Hg	Pb	Cd	Ni
Australia	<1.0	<1-7.0	<0.2-1.8	<100
Kenya	5.0	10	10	300
New Zealand	<1.0	<1-7	>0.2-1.8	<100
Philippines	2.0	50	10	NA

Source:PHILMINAQ. 2008. Water quality criteria and standards for freshwater and marine aquaculture (www.aquaculture.asia/files/PMNQ%20WQ%20standard%202.pdf).

In the case of mercury, the fraction of methylmercury (MeHg) poses the most harm, and the threshold for the commonly analysed total Hg amount has to be adjusted when the MeHg share increases. As an example, in the Canadian Guidelines from British Colombia, the average concentration of total mercury should not exceed 0.02 µg/L (20 ng/L) when the MeHg fraction is ≤0.5 percent of the total mercury concentration. When the share of MeHg is greater than 0.5 percent, the guideline should be stricter (see Table 6.5) in order to prevent undesirable levels of mercury in water from entering the food chain where they would pose a threat to sensitive consumers of aquatic life, especially avian species, i.e. birds (BC MoE, 2001).

Table 6.5. Guideline for total Hg as a function of the percentage of methylmercury

% MeHg (of total Hg)	Guideline (ng/L total Hg)
0.5	20.0
1.0	10.0
2.5	4.0
5.0	2.0
8.0	1.25

Source: BC MOE. 2019. British Columbia approved water quality guidelines: Aquatic life, wildlife & agriculture. Summary report. Victoria, BC, British Columbia Ministry of Environment & Climate Change Strategy, Water Protection & Sustainability Branch

In view of the human health risks from fish farming, priority attention should be given to pathogens, in particular food-borne trematodes and schistosomes (Table 6.6), which are endemic in certain geographic regions. Food-borne trematodes present risks where fish is eaten raw or undercooked, while schistosomiasis (bilharzia) is transmitted through water-skin contact where snail hosts are present in aquaculture ponds.

Concentrations of bacteria are always high in the gut of fish, but relatively seldom in the flesh to be consumed. Cross-contamination from gut contents to edible flesh is rare, but can happen during fish cutting and cleaning. Hygienic processing and cooking reduces such risks.

Table 6.6. Microbiological quality targets for wastewater and excreta use in aquaculture

Media	Viable trematode eggs (number per 100 ml or per gram of dry excreta)	*E. coli* (arithmetic mean per 100 ml or per gram of dry excreta)	Helminth eggs (arithmetic mean per litre or per gram of dry excreta)
Product consumers			
Pond water	Not detectable	$<10^4$	<1
Wastewater	Not detectable	$<10^5$	<1
Treated excreta	Not detectable	$<10^6$	<1
Edible fish flesh or plant parts	Infective metacercariae* not detectable or non-infective	Codex Alimentarius Commission HACCP specifications	Not detectable
Aquaculture workers and local communities			
Pond water	Not detectable	$<10^3$	<1
Wastewater	Not detectable	$<10^4$	<1
Treated excreta	Not detectable	$<10^5$	<1

* The final larval form of a trematode

Source: WHO. 2006. Guidelines for the safe use of wastewater, greywater and excreta in agriculture and aquaculture. Volume III: Wastewater and excreta use in aquaculture. Geneva, World Health Organization.

6.2. Human health risk mitigation

The measures which can be taken to protect health in aquacultural use of wastewater are the same as for agricultural use, namely wastewater treatment, crop/fish restrictions, control of wastewater application, human exposure control and promotion of hygiene. For a sustainable wastewater-fed aquaculture business, the risk of pathogens in general and trematode infections in particular should be prioritized to safeguard human health.

Hazard identification, risk assessment and monitoring and/or control of hazards are important steps in ensuring that the health hazards associated with waste-fed aquaculture are identified in a timely manner and addressed to minimize health risks. Monitoring has three different purposes: validation, or proving that the system is capable of meeting its designed requirements; operational monitoring, which provides information regarding the functioning of individual components of the health protection measures; and verification, which usually takes place at the end of the process to ensure that the system is achieving the specified targets (WHO, 2006). The three functions of monitoring are each employed for different purposes at different times:

- Validation is performed when a new system is developed or when new processes are added, and is used to test or prove that the system is capable of meeting the specified targets.
- Operational monitoring is used on a routine basis to indicate that the processes are working as expected. The process relies on compliance monitoring and simple measurements that can be easily read ensuring that decisions can be made in good time to remedy a problem.
- Verification is employed to show that the end product (e.g., treated wastewater/excreta/pond water, fish or plants) meets treatment targets (e.g., microbial reduction targets) and, reduction targets) and, ultimately, health-based targets. Information from verification monitoring is collected on a periodic basis.

As pathogenic hazards also can occur along the whole food chain, WHO's Sanitation Safety Planning (SSP) manual helps to coordinate stakeholders across the sanitation system and prioritizes improvements and system monitoring based on health risks, including those related to wastewater use in agriculture and aquaculture. The SSP manual (WHO, 2022) is targeted primarily at local-level authorities and can also assist regulators, wastewater utilities, sanitation-based enterprises, community-based organizations, farmer associations and NGOs in implementing a multi-barrier approach for risk reduction, which builds on a Hazard Analysis and Critical Control Point (HACCP) system (WHO, 2006).

There are two key risk groups. Firstly, the quality of water is of paramount importance for the protection of workers in waste-fed aquaculture. As the exact water quality might not be known or vary, farm workers should receive training on all the types of risks associated with wastewater-fed aquaculture. Measures must also be put in place to minimize these risks, including protective clothing, options to bathe, and optimize personal hygiene and medical treatment, or regular prophylaxis in proven endemic areas. Transmission of trematode infections can be prevented only by ensuring that no eggs enter the pond or snail control. Similar considerations apply to the control of schistosomiasis in areas where this disease is endemic. As aquatic snails serve as intermediate hosts for Schistosoma, snail monitoring and environmental snail control (e.g., removing vegetation from ponds and their surroundings) are important safety options. According to WHO (2006), the appropriate helminth quality guideline for all aquacultural wastewater use is ≤1 helminth egg per litre.

The second key risk group is consumers. Here, the key question from a pathogenic risk perspective is whether the selected fish will be cooked or eaten raw (or insufficiently cooked). If well cooked, the pathogenic risk of consumption is very low and there should be no objection to the water source if chemical hazards are unlikely (FAO & WHO, 2019). In all other cases, further risk reduction measures are needed, in particular between "farm and fork". This applies in principle also to fish grown in clean water, as contamination can also occur in markets, fish shops or kitchens. Implementing such a multi-barrier system reduces the pressure on farmers to seek perfectly clean water, which is in many regions simply not feasible. The main risk reduction measures are as follows:

- The first additional step at the fish farm is fish depuration preceding harvesting. This involves the placement of batches of living fish in clean water ponds (for at least two to three weeks) after being taken from the treated wastewater-fed ponds, to allow for the external and internal removal of biological contaminants, odour and physical impurities. The depuration ponds should have a flow-through system with the water changed regularly. Relatively short depuration periods of one to two weeks do not appear to remove bacteria from the fish digestive tract. Depuration has shown to be effective for removing sewage-associated bacteria for shellfish, but not satisfactory for the removal of viruses (Lees, Younger & Dore, 2010).
- Fish smoking can contribute to pathogen removal (Yeboah-Agyepong *et al.*, 2019) and also add value after the fish leaves the farm. There are two main methods – cold smoking and hot smoking. The temperature for cold smoking is generally in the range of 30–40°C, while hot smoking is higher at 80–90°C. Almost all microbes except some pathogenic bacteria are destroyed during hot smoking as the higher temperature cooks and completely dries the fish.

- Fish gutting is a key safety step in markets or kitchens. After rinsing the harvested fish under running tap water, the intact gut of the fish is removed, and the cavity rinsed with safe water before removal of the fish muscle. This sequence avoids cross-contamination between the flesh and the contents of the gut. It is very important to use a different knife to cut the flesh after removing the gut contents. Knives used to process the raw fish should not be used for other purposes such as cutting cooked fish or vegetables.
- Depending on public perception, several options exist that will reduce health risks considerably while maintaining the advantage of nutrient-rich wastewater. These options involve a change in business model, specifically either a change in the cultivated fish or the cultivation target, but also depend on access to an alternative (safe) water source such as groundwater. The main options (Amoah, Gebrezgabher & Drechsel, 2021) include:
    - a shift to another fish species which is not consumed raw, but instead cooked, smoked or grilled;
    - growing only fingerlings in the treated wastewater but adult fish without wastewater, a process that results in significantly less contamination (precautions must be taken to prevent trematode infection because trematodes remain viable as long as the host is alive);
    - growing only broodstock with wastewater from which eggs are extracted for the production of fingerlings, which are then cultured in clean groundwater (the process minimizes hazards associated with the final product as the fingerlings do not have direct contact with the treated wastewater);
    - the production of fish feed such as fast-growing duckweed in the ponds, which transform the nutrient load of the wastewater into protein-rich biomass, while fish is cultivated in safer water outside the WSP system.

Case study 5 in the annex presents a related empirical example realized in a public private partnership in Kumasi, Ghana.

It is important to add that only training of fish farmers or kitchen staff might not result in the adoption of any recommended practices and that e.g., incentives might be needed to facilitate behaviour change (Drechsel, Qadir & Galibourg, 2022).

6.3. Environmental risks and risk mitigation

Aquaculture can contribute significantly to the pollution of the aquatic environment at various stages including pond construction, pond treatment, water intake, stocking, nursing, water exchange, sludge discharge, harvesting and pond emptying. This section highlights problematic farming practices from a pollution perspective using the examples of Pangasius and shrimp farming in Viet Nam (Nguyen, 2017), and also explores the opportunities that integrated rice-fish farming offer (Box 6.1).

Box 6.1. Integrated crop-fish systems and water quality

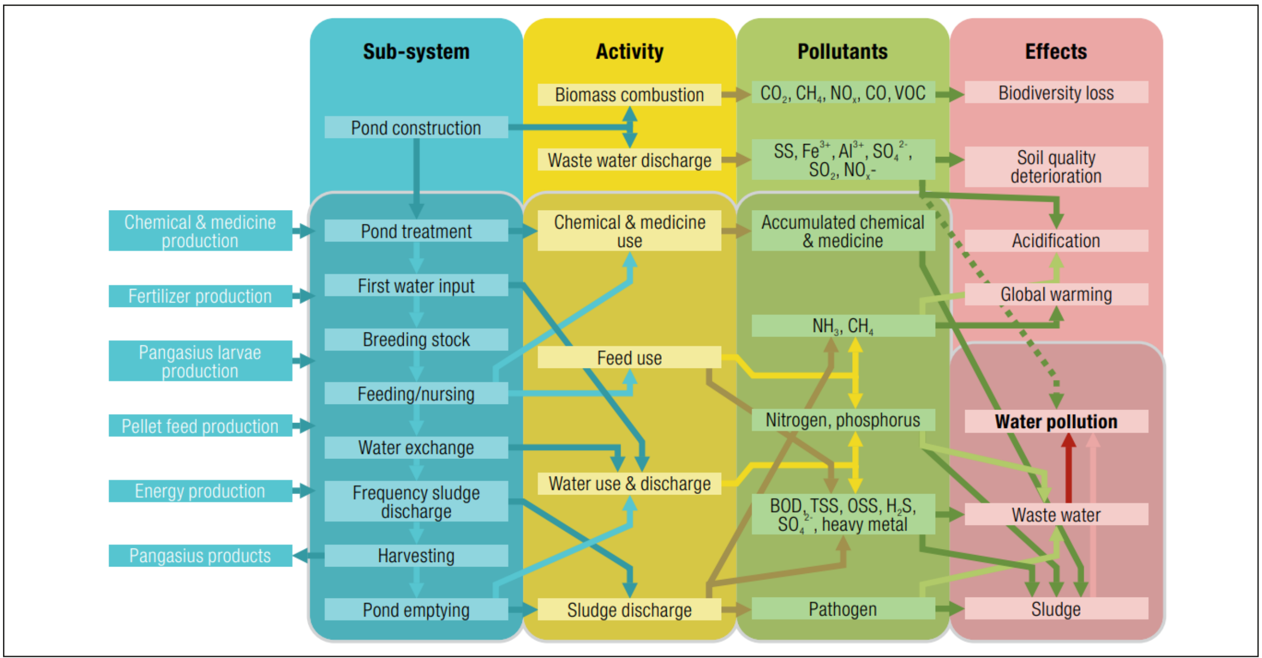
Irrigated rice schemes often involve the cultivation of fish in an upstream irrigation tank (reservoir); however, opportunities may exist for an integrated rice-fish culture in which fish live directly in the rice fields. Although this process requires careful water quality management, it presents significant onsite and offsite benefits.

Promoting integrated fish-crop systems in which fish waste serves as a fertilizer for the crops can be a cost-effective way of minimizing water pollution at the system level. Integrated aquaculture-agriculture (IAA) can also limit pesticides use. A field survey in China demonstrated that although rice yield and rice-yield stability are similar in rice-fish (RF) systems and rice monoculture (RM), RF requires 68 percent less pesticide and 24 percent less chemical fertilizer than RM. A field experiment confirmed this result: fish reduce rice pests and rice favours fish by moderating the water environment. The results also indicate a complementary use of nitrogen (N) between rice and fish in RF, resulting in low N fertilizer application and low N release into the environment (Xie *et al.*, 2011). A study in Myanmar's Ayeyarwady delta showed no impact on paddy yields but a 25 percent increase in economic returns for the same land area from fish in addition to multiple nutritional benefits (Dubois *et al.*, 2019). Studies from Bangladesh and Viet Nam also demonstrated that rice-fish farming provides a competitive and sustainable alternative to intensive rice-farming if the farmer restricts the use of pesticides. This approach not only helps to reduce production costs, but also decreases negative environmental and health impacts (Ahmed and Garnett, 2011; Berg and Tam, 2018).

6.3.1. Pangasius (*Pangasius hypophthalmus*, *P. bocourti*) are facultative air-breathers, which means that they can withstand dissolved oxygen at levels as low as 0.05–0.10 mg/l, high turbidity and highly polluted water, due to an ability to spend the majority of their time near the surface (<1m) where DO is closer to the recommended range of 2.5–7.5 mg/l) (Waycott, 2015).

To maintain water quality and fish health in densely stocked ponds, the water is chemically as well as biologically treated using a large array of chemicals, including antibiotics, biocides, vitamins and digestive drugs (Nguyen *et al.*, 2015). Pond water in high density systems is exchanged on a frequent basis (from weekly to twice a day depending on fish age) to prevent toxic substances such as ammonia, nitrite, hydrogen sulphide or pathogens from accumulating as a result of wasted feed and fish excreta. Ponds also release considerable volumes of sludge when the pond sediment is excavated. Related management options are central for an environmental impact assessment (Figure 6.1).

Figure 6.1. Environmental impact analysis for Pangasius farming



Source: Nguyen, C.V. 2017. An overview of agricultural pollution in Vietnam: The aquaculture sector. Prepared for the World Bank, Washington, DC; after Anh, P.T., Kroeze, C., Bush, S.R. & Mol, A.P.J. 2010a. Water pollution by pangasius production in the Mekong Delta, Vietnam: Causes and options for control. Aquaculture Research, 42: 108–128.

As pond water constitutes a point source of pollution, it should be collected and treated according to national regulation standards before being discharged into open water bodies. However, this requirement is seldom enforced, especially as land suitable for fish farming can be very expensive, and farmers try to minimize the area devoted to waste treatment systems such as sedimentation or wastewater treatment ponds.

Anh *et al*. (2010a) suggest two approaches for ameliorating the impacts of water pollution, contaminated sediment and disease spread: (i) waste prevention and minimization at source, and (ii) treatment and/or onsite or offsite recycling and re-use of waste materials in other production processes (Table 6.7).

Although national regulations have become more rigorous in Viet Nam, market incentives have seemingly proven more effective in motivating farmers. Since 2010, a growing number of intensive Pangasius farms in Viet Nam have improved their wastewater and other management practices to gain access to export markets that require certification under standards, such as those established by **GLOBAL**G.A.P and the Aquaculture Stewardship Council (ASC). In this context, private agribusiness companies have become increasingly proactive in working with farmers, collectors, wholesalers and processors in the value chain to control efficiency at every step of production. Under contract farming arrangements, farmers are typically required to follow the guidance/instructions of agribusinesses, especially on the use of inputs, leading to improvements in both product and environmental health (Nguyen, 2017). The need for such controls and certificates became clear with reports in European media that imported Pangasius is highly toxic. However, toxicological risk assessment failed to find related evidence of pesticides and antibiotics in sufficient amounts to pose a risk (Murk *et al*., 2018).

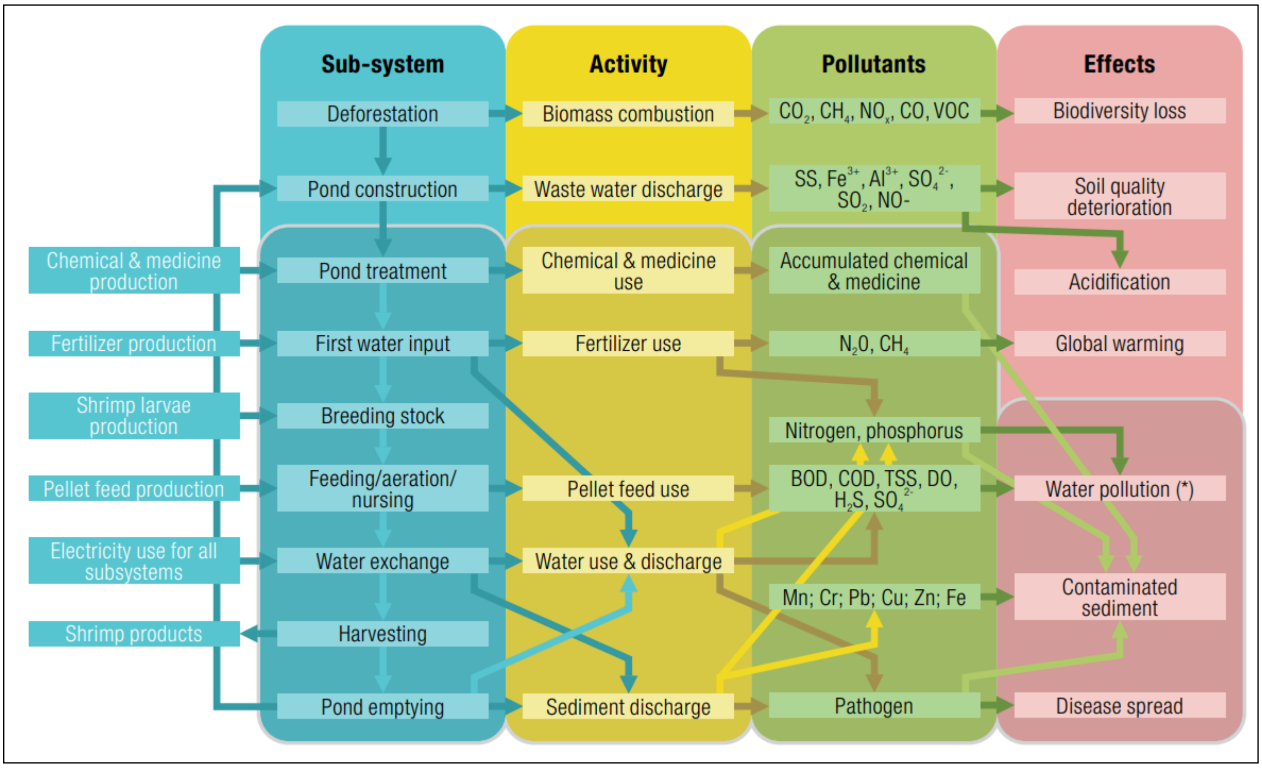
Table 6.7. Options for the reduction of water pollution by Pangasius farming in the Mekong Delta

Name of option	Description of the option	Pollutants or problems reduced	Subsystem and activity to be applied	Remarks	Currently applied/ Costs
Waste prevention and minimization at source					
Water use reduction	Techniques for cleaning water so that less pumping is needed: ozone aeration and probiotic use	Volume of wastewater	Water refreshment	Reduce volume of water use and wastewater	Hardly applied:
Feed use reduction	More efficient feed use: replace homemade feed by good quality pellet feed	BOD, COD, SS	Feeding	Reduce surplus feed sediment	At least half of the farms use homemade feed; pellet feed more expensive
Chemical, medicine use reduction	Techniques for efficient use of chemicals and drugs	Accumulated chemicals and drugs; anti-microbial resistance	Pond treatment/ nursing	Reduce amount of accumulated chemicals and drugs in the sludge	Not applied; if applied appropriately, positive benefit-cost ratio
Treatment of inlet water and good farm cleaning	Techniques for cleaning farms and filtering inlet water	Risk of pangasius disease and dead fish	First water input, Water intake and pond emptying	Reduce risk of disease and dead fish, (one of the cause of water pollution)	Filtering is not applied; relatively costly
Treatment and reuse of water stream					
Sludge treatment in sedimentation ponds	Using a pond for settling the sludge, the effluent can be treated as wastewater	All substances	Frequency sludge discharge and pond emptying	Dewatering sludge can be used for leveling of low land or putting in fruit garden	<10% of farms applied; costs are relatively low if land is available
Treatment of wastewater in constructed wetlands	Sub-surface horizontal flow constructed wetland is possible	All substances	Water exchange pond emptying and effluent from sediment pond	Land scarcity is a challenge	Not applied; costs are moderate if land is available
Reuse wastewater with optimization of the discharge design	Land treatment of wastewater in agriculture	All substances	Water exchange and pond emptying	Investment costs can be considerable, the additional operational costs are relatively low.	Pilot for use of wastewater in rice field, no optimization of discharge design yet

Source: Anh, P.T., Kroeze, C., Bush, S.R. & Mol, A.P.J. 2010a. Water pollution by pangasius production in the Mekong Delta, Vietnam: Causes and options for control. Aquaculture Research, 42: 108–128.

6.3.2. Shrimp farming. The effects of shrimp farming on the environment vary in relation to the shrimp varieties and different farming practices used in their cultivation. Black tiger shrimp, for example, are raised in Viet Nam in either intensive or extensive systems, while white-leg shrimp are exclusively raised in intensive systems. A larger proportion of intensive operations are characterized by higher stocking density and the use of pelleted feed, whereas a lower share of extensive systems involve little, if any, feeding to supplement what is naturally available. White-leg shrimp farms make intensive use of feeds, pond chemicals (pesticides, etc.) and drugs (in particular different antibiotics) against diseases. During harvest, most intensive farms discharge pond water to wastewater treatment systems, whereas most semi-intensive farms drain pond water to the water bodies without proper treatment. In terms of solid waste, the rate of sediment accumulation in intensive shrimp ponds depends on stocking density and the type of commercial pelleted feeds that are used. Pond muds/sludge are flushed to storage sites where they may receive treatment, but in other cases are discharged to canals or rivers, which are important variations for an environmental impact assessment (Figure 6.2).

Figure 6.2. Environmental impact analysis for shrimp farming



Source: Nguyen, C.V. 2017. An overview of agricultural pollution in Vietnam: The aquaculture sector. Prepared for the World Bank, Washington, DC; after Anh, P.T., Kroeze, C., Bush, S.R. & Mol, A.P.J. 2010b. Water pollution by intensive brackish shrimp farming in South-East Vietnam: Causes and options for control. Agricultural Water Management, 97: 872–882.

Intensive shrimp production in Viet Nam has been estimated to generate about 4.4 billion m^3 of wastewater in 2014, including 25 344 tonnes of N (19 800 tonnes from wastewater and 5 544 tonnes from sludge) and 6 336 tonnes of P (2 442 tonnes from wastewater and 3 894 tonnes from sludge). It is estimated that approximately 75 percent of this wastewater was discharged to local rivers in coastal areas of the Mekong Delta (Nguyen, 2017).

A 2015 study estimated that intensive shrimp farms in Vietnam were devoting 17 percent of their farmland, on average, to treatment ponds. Techniques include the use of algae, bacteria and tilapia to remove organic contents, as well as pond rotations or closed water recirculation systems to avoid incoming diseases. The rate of environmental compliance has increased significantly from less than 10 percent in 2013 to over 50 percent in 2016 (Long & Hien, 2015; Nguyen, 2017).

Similar to Pangasius farming, Anh *et al.* (2010b) suggest two approaches for ameliorating the impacts of water pollution, contaminated sediment and disease spread: (i) waste prevention and minimization at source, and (ii) treatment and reuse of effluent streams (see Table 6.8 and Table 6.9).

Table 6.8. Waste prevention and minimization at source (shrimp farming)

Options	Description	Pollutions/ problems reduced	Sub-System to be applied	Problems reduced			Remarks
				WP	CS	DS	
Water use reduction	Ozone aeration	BOD, COD, pathogens, water use, wastewater generation	Aeration/ water	+++	+++	+++	Need a technical transfer to farmer; could be limited to this last grow out phase
Feed use reduction	More efficient feed use: careful in checking optimum use of feed	BOD, COD, pathogens	Feeding	++	++	++	Information exchange on experiences with different types of feeds needed, and exact information on composition of feed
Chemical, medicine use reduction	Better guidelines and monitoring for correct use of chemical and medicine are needed	Accumulated chemical and medical components in water and sediment	Pond treatment/ nursing	+	+	+	Could reduce build-up of anti-microbial resistance

WP: Water pollution; CS: Contaminated sediment; DS: Disease spread; + indicates a moderate improvement, ++ a considerable improvement, +++ a large improvement.

Source: Anh, P.T., Kroeze, C., Bush, S.R. & Mol, A.P.J. 2010b. Water pollution by intensive brackish shrimp farming in South-East Vietnam: Causes and options for control. Agricultural Water Management, 97: 872–882; modified.

Table 6.9. Treatment and reuse of effluent streams from shrimp farming

Options	Description	Sub-System to be applied	Problems reduced			Remarks
			WP	CS	DS	
Treatment and reuse of sediment	Production of compost or soil conditioner from sediment. Application of probiotics to pond sediments could accelerate decomposition	Sludge discharge	+	+++	+	Local research required, e.g., to optimize retention time vs. land requirements. For mangroves to remove nutrients about 2–3 ha are needed per hectare of semi-intensive shrimp ponds.
Treatment and reuse of wastewater	Use mangrove forest wetlands or constructed wetlands	Wastewater discharge	++	+	+	
Wastewater and sediment discharge	Optimization of farm design to ensure that wastewater does not return directly to the surface water.	Water and sediment discharge	+	+	++	

WP: Water pollution; CS: Contaminated sediment; DS: Disease spread; + indicates a moderate improvement, ++ a considerable improvement, +++ a large improvement.

Source: Anh, P.T., Kroeze, C., Bush, S.R. & Mol, A.P.J. 2010b. Water pollution by intensive brackish shrimp farming in South-East Vietnam: Causes and options for control. Agricultural Water Management, 97: 872–882; modified.

Based on the scale and potential of intensive shrimp farming in Vietnam the most viable options for waste reduction include more efficient feed use and ozone aeration. For the reduction of feed it is important that adequate and sufficient information is available to farmers and that the government can efficiently regulate the quality and composition of feeds. Aeration is noted as a particularly suitable technology given the low level of expense needed to implement it in existing intensive systems. Options for waste treatment through sediment reuse and the construction of artificial wetlands are both viable options if the economics can be justified to farmers. Wetland construction, although practiced on some farms, remains difficult to implement due to the lack of land available to farmers, especially in peri-urban areas (Anh *et al.*, 2010b).

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