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WATER QUALITY IN AGRICULTURE: Risks and risk mitigation

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Chapter 8

Ecological risks and risk mitigation measures related to water quality and agriculture

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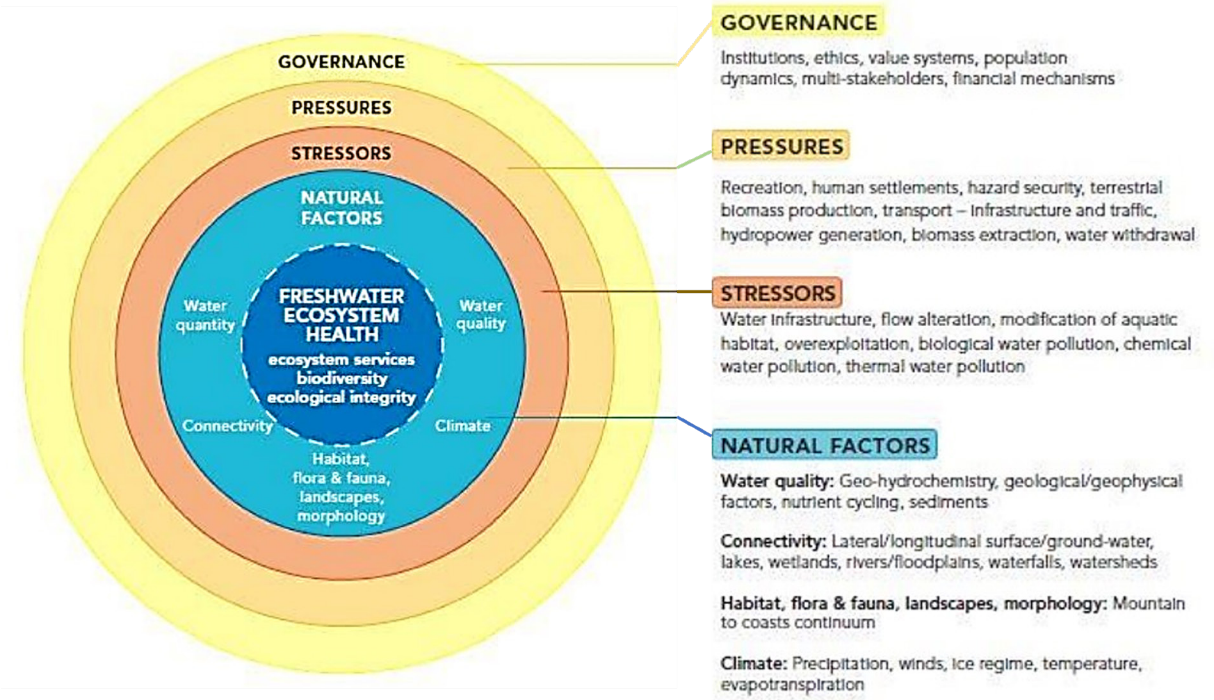
Freshwater ecosystem health is under multiple pressures (Fig 8.1) with water pollution and quality being a key factor. Farming is in this context an intrusion on the natural habitat and landscape of the environment. The farming of crops (particularly mono-cropping practices) is not only affecting biodiversity but also changes natural water flows and can negatively affect water quality (APO, 2016). While pollution of the natural environment – and water bodies in particular – derives from various point and non-point sources including urban wastewater, this chapter focuses on pollution from agricultural activities, i.e., an aspect over which farmers have control. Possible impacts from pollution related to water quality can be various and relate to both irrigated and non-irrigated (rainfed) cropping, as well as fish and livestock farming.

Figure 8.1. Freshwater ecosystem health under pressure



Source: UNEP. 2018. A framework for freshwater ecosystem management. Volume 4: Scientific background. Nairobi, United Nations Environment Programme.

The most common water pollution pathways in agricultural areas are erosion and water body siltation, farm surface runoff contaminated with fresh manure, fertilizers or pesticides, and saline irrigation drainage water affecting downstream ecology. Nitrogen and phosphorus overuse can also pose a significant threat to environmental health, biodiversity and ecosystem services, especially in locations with high fertilizer application rates.

This chapter briefly describes these risks as well as common indicators and risk mitigation measures of relevance to agriculture. In so doing, it aims to demonstrate the need for a systems or landscape approach when considering downstream impacts through good agricultural practices.

8.1. Risks of relevance to ecology

Rivers, streams and wetlands in general are the receptacle of all kinds of pollution, and constitute pathways for pollutants to coastal and marine waters or lakes. According to UNEP (2016), in Africa, Asia and Latin America, one-third of all rivers are affected by severe pathogen pollution, one-seventh by severe organic pollution, and one-tenth by severe and moderate salinity pollution. Inorganic pollution represents a particular threat to ambient water quality occurring when an excess of easily biodegradable wastes (e.g. nutrients such as phosphorus, nitrogen and potassium from agricultural land, livestock farming or aquaculture) enters rivers and lakes through run-off and erosion (UN Water, 2016). Global estimates suggest that soil erosion by water is responsible for annual fluxes of 23–42 Mt of nitrogen and 14.6–26.4 Mt of phosphorus from agricultural land (FAO & ITPS, 2015).

Nitrates and phosphates can stimulate excessive plant growth and lead to eutrophication – the over-productivity of plant organisms in water – resulting in the creation of algal blooms and the depletion of oxygen concentrations, which in turn decreases aquatic biodiversity (UNEP, 2016; UN Water, 2016). Observed consequences of eutrophication in freshwater wetland systems include shifts in vascular plant species composition due to an increase in above-ground production, a decrease in local or regional biodiversity, growth in the competitive advantage of aggressive/invasive species, loss of nutrient retention capacity (e.g. carbon and nitrogen storage, changes in plant litter decomposition) and shifts in macroinvertebrate composition along an eutrophication gradient (USEPA, 2008). Conservative estimates of the costs of eutrophication amount to USD 1 billion in annual losses for European coastal waters and USD 2.4 billion for lakes and streams in the United States (Wurtsbaugh, Paerl & Dodds, 2019).

Aside agro-chemical transport through run-off and erosion, water quality problems can also arise from suspended soil particles themselves, which cause turbidity and siltation of water bodies, leading eventually to increased sedimentation of reservoirs, for example. While soil erosion and sediment transport are natural processes, deforestation, land clearance for agriculture and inappropriate agriculture practices can substantially increase the amount of suspended solids and turbidity in the water, which can lead to multiple undesirable effects for aquatic plants, algae, invertebrates and fish (Dunlop, McGregor & Horrigan, 2005). Increased turbidity may limit, for example, the growth of bottom-rooted aquatic plants and favour the growth of algae. It can result in reduced visibility for animals that use sight to find food or hide from predators, affect spawning habitats and provoke respiratory problems in fish. Increased sedimentation also leads to infilling of reservoirs, clogging of waterways and alteration of flow patterns (FAO, 2018).

Some 30 percent of the world's freshwater stocks are found beneath ground that is tapped to supply water for domestic and agricultural needs (UNEP, 2010). Depending on the characteristics of farm soils and their underlying geology, groundwater is less exposed to pollutants than surface waters; however, they can be heavily impacted when pollutants infiltrate coarse textured substrates with limited filtration. Contamination of soils and groundwater can be caused by irrigation practices leading to salinity through nitrate and pesticide leaching, or the accumulation of chemicals or pathogens where wastewater is used.

Wetlands can function as natural "kidneys" that filter and improve water quality, attenuate and moderate floodwater flows, replenish groundwater and recharge underlying aquifers. In addition to providing multiple ecosystem services, wetlands also support biodiversity. However, many wetlands have been degraded by excessive volumes of contaminants, or encroachment, diminishing their capacity to improve water quality and provide other services.

8.2. Water quality and ecosystem health criteria

Aquatic life water quality indicators and criteria are essential for the protection of fish and wildlife. In general, indicators for freshwater ecosystems can be categorized in terms of quantity (e.g., flow volumes), quality (e.g., dissolved oxygen, specific nutrients or toxicants), habitat (e.g., substrates, bank stability or riparian vegetation), and biological criteria (e.g., fish, invertebrates, algae) (UNEP, 2018).

Criteria, in particular those showing concentrations of pollutants, are typically expressed in two forms to address unacceptable adverse effects from both short-term (acute) and long-term (chronic) exposure, with the objective of protecting aquatic life from lethal as well as sub-lethal effects, like immobility, slower growth, or reduced reproduction.

Acute and chronic criteria for aquatic life addressing magnitude, duration, and frequency are expressed with two terms (USEPA, 2021):

- Criterion Maximum Concentration (CMC). An estimate of the highest concentration of a material in ambient water to which an aquatic community can be exposed briefly without resulting in an unacceptable adverse effect. This is the acute criterion.
- Criterion Continuous Concentration (CCC). An estimate of the highest concentration of a material in ambient water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable adverse effect. This is the chronic criterion.

The USEPA (2022) national aquatic life criteria recommendations represent specific CMC and CCC levels of inorganic and organic chemicals or conditions in a fresh and salt water body not expected to cause adverse effects to aquatic life.

An alternative framework has been presented by UNEP (2018) based on various national and international guidelines. In Table 8.1 values for physical and chemical indicators of freshwater ecosystem quality are proposed which are indicative of (i) high ecosystem integrity, and (ii) extreme impairment, respectively. The first benchmark value will separate freshwater ecosystems of high integrity (Category 1) from ecosystems in worse quality status. The second benchmark demarcates the low end of the quality continuum: Ecosystem quality status should be above this threshold, otherwise the water body would lose with high probability aquatic diversity and beneficial use and ecosystems will face severe reduction or complete loss of Ecosystem Services (Category 4).

Table 8.1. Proposed physico-chemical benchmarks for (surface) freshwater ecosystems. Annual average total concentrations, unless otherwise indicated.

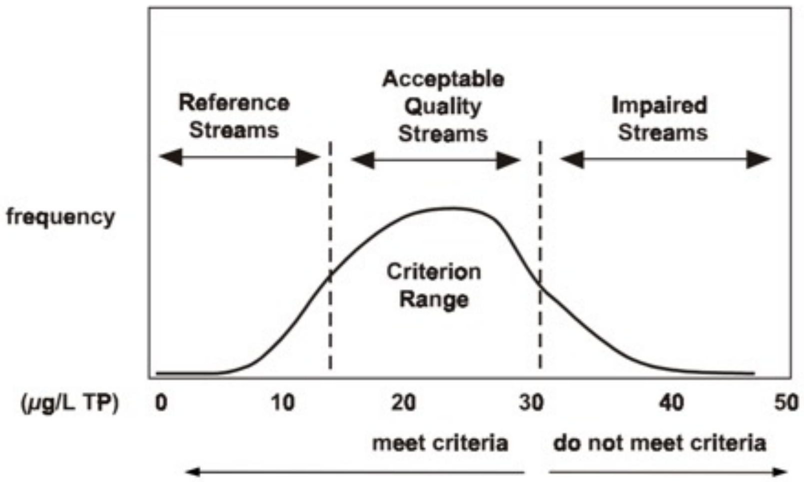
Parameter	High Integrity (Category 1)[1]	Extreme impairment (Category 4)
Dissolved oxygen (DO) saturation (%)	80-120	<30 or > 150
Dissolved oxygen concentration (DOC) (mg/l)	7.3-10.9 [2]	<3 or > 13.6 [2,3]
(Optional) BOD_5 (mg/l)	-	>10
Total Phosphorous (TP) (μg/l) - Lakes and reservoirs - Rivers and streams	 <10 <20	 >125 >190
Total Nitrogen (TN) (μg/l) - Lakes and reservoirs - Rivers and streams	 <500 <700	 >2500 >2500
Chlorophyll (μg/l) - Lakes and reservoirs - Rivers and streams	 <3.0 <5.0	 >165 >125
pH	6.5-9.0	<5.0
Temperature	No deviation from background value or reference system or optimum temperature ranges of relevant species	Large deviations from background value or the thermal tolerance range for characteristic species
Un-ionized Ammonia (μg NH_3/l)	15 [5]	100 [5]
Aluminum (μg/l) at pH <6.5 at pH >6.5	 5 10	 - 100
Arsenic (μg/l)	10	150
Cadmium (μg/l) [4]	0.08	1.0
Chromium (μg/l) [4] Cr III Cr VI	 10 1	 75 40
Copper (μg/l) [4]	1	2.5
Lead (μg/l) [4]	2	5
Mercury (μg/l) [4]	0.05	1.0
Nickel (μg/l) [4]	20	50
Zinc (μg/l) [4]	8	50

[1] Natural sources and geographical conditions may cause natural background values that differ from the benchmarks for high integrity. Instead of these benchmark values, natural background concentrations may be used for setting local criteria for high integrity.
[2] Dissolved oxygen concentration varies depending on temperature, pressure and salinity; benchmarks are for freshwater at sea level (760 mm Hg) and 20^{0}C based on the DO%.
[3] Daily average.
[4] Applicable for waters with low hardness (< 6 mg/l $CaCO_3$). In case of higher hardness, the benchmark values may be somewhat higher.
[5] Corresponding total ammonia (NH_3 + NH_4^+) concentration depend on pH and temperature. At pH 7.5 and 20^{0}C the benchmarks for total ammonia- N are 1 000 μg/l and 6 641 μg/l, respectively.

Source: UNEP. 2018. A framework for freshwater ecosystem management. Volume 4: Scientific background. Nairobi, United Nations Environment Programme.

As Table 8.1 shows, there is often a grey area between good and highly impaired water quality. Indeed, some criteria depend on other water quality characteristics, such as alkalinity, hardness, pH, suspended solids and salinity, which alter inter alia the biological availability and/or toxicity of certain chemicals (see footnotes for Table 8.1). As a result, water quality varies naturally with a site's specific physical, chemical and/or biological conditions, depending among others on geology and season (e.g. the sediment load is higher after rains than before). This natural variation constitutes a significant challenge for applying 'generic' thresholds to a local context. Thus, for any work with water quality criteria, USEPA (2000, 2008) and UNEP (2018) recommend to first define a natural baseline (Figure 8.2).

Figure 8.2. Frequency distribution divided into high-quality reference streams (baseline), acceptable quality streams and impaired (eutrophic) streams



Source: USEPA. 2000. Nutrient criteria technical guidance manual: Rivers and streams. Washington, DC, Environmental Protection Agency

8.3. Risk mitigation measures

Applying an ecosystem health approach necessitates adopting precaution as a fundamental principle to enable water bodies to provide and secure their respective ecosystem services in a sustainable manner. The precautionary principle contrasts with the "impair-and-then-repair" paradigm, which remains common practice in water resources engineering and development (UNEP, 2018). As water quality monitoring has a low coverage in many regions, a precautionary approach focuses first of all on preventing possible harm, which requires awareness about ecosystem services and downstream impacts. A key advantage of the precautionary approach is that farmers have no need to access laboratories or to understand the water quality parameters discussed above. This also represents an advantage where emerging contaminants such as pharmaceutical residues are concerned, as laboratories in many low-income countries lack sufficient equipment and no thresholds are yet in place to quantify the associated risk.

To prevent erosion and pollution before they impact waterways and water quality, FAO, USDA and many others have developed critical control points (e.g. Table 8.2) and good agricultural practices (Table 8.3). These help avoid over-fertilization, increases in soil salinity and pesticide-related ecological trade-offs, among others (e.g. FAO, 2007, 2010). Similar guides exist for livestock (e.g. FAO & IDF, 2004; FAO & OIE, 2009) and fish farming (e.g. ASEAN, 2015). The spectrum of good practices is vast and requires adaptation to local circumstances and farmer's limitations and opportunities (e.g. in view of the reduction or replacement of chemicals or the availability of plants for hedgerows to reduce runoff).

Table 8.2. Examples of hazards from livestock keeping and corresponding control points

Chemical hazards	Control points
Chemical contamination of environment, feed and water	• Farm location • Animal movement • Use of agricultural chemicals • Feed and water quality • Equipment and building materials • Hygiene practices
Toxins of biological origin (plants, fungi, algae)	• Feed, pasture, and water quality • Farm location • Animal movements • Feed production, storage and • Transport
Residues of veterinary medicines and biologicals (incl. medicated feed and water)	• Treatment of animals • Sales and prescription control • Record keeping • Residue control • Quality of feed and water

Source: FAO & OIE. 2009. Guide to good farming practices for animal production food safety. Rome

Where polluted water leaves livestock or fish farms, on-site water treatment should be considered, for example through the construction of artificial wetlands (Wang *et al.*, 2018). Farmers can also minimize pollution affecting their soil and crop health through low quality irrigation water, by adopting water efficient irrigation practices which minimize the volumes of water needed. Table 8.3 provides an overview of possible water quality impacts from agriculture on water bodies, and examples of good agricultural practices to avoid or reduce risks for water quality and ecology. Specific challenges for crops and soils and related mitigation measures are also addressed in Chapters 4 and 5 dedicated to pathogenic and chemical risks including salinity.

Table 8.3. Agricultural impacts on water quality and related mitigation options

On-farm activities	Challenges for water bodies	Good agricultural practices for risk mitigation
Tillage/ ploughing	Depending on topography and rainfall, increase of runoff, sedimentation and turbidity: phosphorus and pesticides adsorbed onto sediment particles; siltation of river beds and loss of habitat, spawning grounds, etc.	Minimize erosion and farm runoff through cover crops, mulching, hedgerows, etc., consider zero-tillage.
Fertilizer use and manure spreading	Depending on dosage, slope and soil conditions, possible runoff resulting in contamination of receiving waters with phosphorus and nitrogen, leading to water eutrophication, excess algal growth, water deoxygenation and loss of fish biodiversity), as well as contamination through pathogens and antibiotics from manure. Leaching of nitrates to groundwater potentially threatening public health.	Use locally recommended fertilizer dosages. Prevent farm runoff, for example by building anti-erosion structures and planting grass rows across slopes.
Pesticide application	Runoff of pesticides leads to contamination of water bodies affecting their biota, including possible public health impacts from eating contaminated fish.	Apply Integrated Pest Management (IPM) for pests and diseases, including the use of biological pesticides where possible. Use only locally recommended dosages and prevent farm runoff.
Irrigation infrastructure	Changing the natural patterns of river flow and the creation of irrigation dams can block the movements of fish and affect whole ecosystems.	Adopt environmentally sound standards to make decisions regarding location, type and operation of future reservoirs and dams.

Irrigation water management (effects on farm soils, crops and human health)	Use of low-quality water, such as (diluted) wastewater affecting soil and crop health and potentially consumers; possible bioaccumulation of chemicals in crops or fish. Runoff of chemicals to surface waters or infiltration into groundwater affecting downstream water bodies and communities Too low/high irrigation amounts causing salt accumulation in the rooting zone or groundwater.	Use safe irrigation practices and a multi-barrier approach to minimize contaminant transfer. Prevent uncontrolled drainage. Build natural water filtration or sedimentation infrastructure (wetlands, bunds, ponds, terraces) to maximize on-plot water use (and minimize run-off). Adjust irrigation techniques, intervals and amounts to water and soil salinity, reclamation of saline or sodic soils; use of more resistant crops.
Clearcutting, afforestation and reforestation	Changes in land cover can increase soil exposure, compaction, runoff and sedimentation, alter hydrological flows and provoke a decline in riparian areas affecting water and land quality and biodiversity. Soil compaction limits water infiltration.	Implement anti-erosion measures; ensure the conservation of valuable plants (e.g. fruit trees). Use good silvicultural practices, such as the watershed management module of FAO's Sustainable Forest Management (SFM) Toolbox (FAO, 2017).
Animal husbandry, feedlots, animal corrals and their waste management	Contamination of waterbodies with pathogens (bacteria, viruses, etc.) leading potentially to chronic public health problems. Also contamination by metals, antibiotics and other pharmaceuticals contained in livestock urine and faeces. Potential leaching of nitrogen, metals, etc. to groundwater.	Use chemicals (fertilizers, agricultural and veterinary chemicals, pesticides, etc.). appropriately to avoid contamination of the local environment. Have a waste (water) management system in place. Capture and treat farm off-flow before it enters natural water bodies.
Aquaculture, fish feeding and waste management	Release of pond water with high levels of nutrients (through feed and faeces) to surface water and groundwater leading to serious eutrophication. Within-lake cage farming is considered one of the major stressors on lake water quality. Organic and nutrient loading can easily result in organic accumulation in the sediment with lake water quality deterioration, accelerating the process of lake eutrophication and toxic cyanobacterial bloom. Introduction of exotic species can severely affect local biodiversity.	Use chemicals (fertilizers, agricultural and veterinary chemicals, pesticides, etc.). appropriately to avoid contamination of the local environment. Have a waste (water) management system in place. Capture and treat farm off-flow before it enters natural water bodies.
Aquaculture, fish feeding and waste management	Release of pond water with high levels of nutrients (through feed and faeces) to surface water and groundwater leading to serious eutrophication. Within-lake cage farming is considered one of the major stressors on lake water quality. Organic and nutrient loading can easily result in organic accumulation in the sediment with lake water quality deterioration, accelerating the process of lake eutrophication and toxic cyanobacterial bloom. Introduction of exotic species can severely affect local biodiversity.	Avoid over-feeding/stocking, and observe outflow guidelines for pond effluents. In the example of Thailand (ACFS, 2009), the law requires effluent to be treated prior to discharge. If farm size is over 1.6 ha, the effluent parameters shall meet the following specification: • BOD not above 20 mg/l. • Suspension solid not above 80 mg/l. • NH_3-N not above 1.1 mg/l. • Total Nitrogen not above 4.0 mg/l. • Total Phosphorus not above 0.5 mgP/l. • pH 6.5-8.5 Exotic fish species should not pose a risk to the natural biodiversity and ecosystem health.

Source: Authors' own elaboration

8.4. Adopting good agricultural practices

To facilitate the adoption of good agricultural practices, farmers have to be trained, and their awareness as a community member on upstream-downstream impacts and ecosystem services increased. However, training alone might not translate into behaviour change (Drechsel, Qadir &, Galibourg, 2022). Incentive systems, like payments for environmental services (PES), might be required where without tangible benefits farmers do not accept responsibility for downstream impacts of their actions. What can trigger behaviour change has, however, to be explored in each local context. Another possible incentive for the adoption of good agricultural practices is the increasing availability of national and international certification programmes or schemes. Increasing consumer demand for confidence in safe and sustainable food, and the need among retailers for a dependable tool to evaluate suppliers underline the importance of certification. Such forms of certification can be voluntary or mandatory, as in the case of outgrowers or export crops farmers. Even where voluntary, local farms can request certification of their good agricultural practices. In such cases, farm audits are carried out to ensure that farms are complying with the certification requirements (SFA, 2019; APO, 2016; QUACERT, 2020). Some schemes ask for farm conservation plans (i.e. a written action plan on the conservation of flora, fauna and natural resources in the wider farm area). Certification can provide several benefits for farmers, such as better and easier access to the market and clear agreements and dialogue with retailers. However, where consumers' ecological or risk awareness is low, certification might only reach domestic niche markets but remains an option for export crops (Keraita & Drechsel, 2015).

References

ACFS. 2009. *Good aquaculture practices for freshwater aquatic animal farm.* Bangkok, National Bureau of Agricultural Commodity and Food Standards (available at www.acfs.go.th/standard/download/eng/GAP_Freshwater_clean.pdf).

APO. 2016. *Manual on good agricultural practices (GAP).* Tokyo, Asian Productivity Organization (available at www.apo-tokyo.org/publications/wp-content/uploads/sites/5/Manual-on-Good-Agricultural-Practices-2016.pdf).

ASEAN. 2015. *Guidelines on ASEAN good aquaculture practices (ASEAN GAqP) for food fish.* Jakarta, ASEAN Secretariat (available at https://asean.org/book/guidelines-on-asean-good-aquaculture-practices-asean-gaqp-for-food-fish/).

Drechsel, P., Qadir, M. & Galibourg, D. 2022. The WHO Guidelines for Safe Wastewater Use in Agriculture: A Review of Implementation Challenges and Possible Solutions in the Global South. *Water* 2022, 14, 864. https://doi.org/10.3390/w14060864.

Dunlop, J., McGregor, G. & Horrigan, N. 2005. *Potential impacts of salinity and turbidity in riverine ecosystems: Characterization of impacts and a discussion of regional target setting for riverine ecosystems in Queensland*. Queensland, Australia, Department of Natural Resources and Mines.

FAO. 2007. *Guidelines "Good Agricultural Practices for Family Agriculture".* Antioquia, Colombia, FAO Regional Office for Latin America and the Caribbean, Departmental Program on Food and Nutritional Security (available at www.fao.org/3/a-a1193e.pdf).

FAO. 2010. Good agricultural practices (GAP) on horticultural production for extension staff in Tanzania: Training manual. Rome (available at www.fao.org/3/i1645e/i1645e00.pdf).

FAO. 2017. *Sustainable forest management (SFM) toolbox.* Rome (available at www.fao.org/sustainable-forest-management/toolbox/modules/watershed-management/in-more-depth/en).

FAO. 2018. *More people, more food, worse water? A global review of water pollution from agriculture*. FAO, Rome and IWMI, Colombo (available at www.fao.org/3/ca0146en/CA0146EN.pdf).

FAO & IDF. 2004. *Guide to good dairy farming practice.* Rome, FAO & International Dairy Federation (available at www.fao.org/3/Y5224E/y5224e00.htm).

FAO & ITPS. 2015. *Status of the World's Soil Resources (SWSR): Main Report*. Rome, FAO & Intergovernmental Technical Panel on Soils.

FAO & OIE. 2009. *Guide to good farming practices for animal production food safety*. Rome (available at www.fao.org/3/i0482t/i0482t00.pdf).

Keraita, B. & Drechsel, P. 2015. Consumer perceptions of fruit and vegetable quality: certification and other options for safeguarding public health in West Africa. Colombo, Sri Lanka: International Water Management Institute (IWMI) 32p. (IWMI Working Paper 164) [doi: 10.5337/2015.215]

QUACERT. 2020. *Vietnam Certification Centre*. Hanoi, Ministry of Science and Technology (available at www.quacert.gov.vn/en/good-agriculture-practice.nd185/vietgap-standard.i88.html

SFA. 2019. *Good aquaculture practices for fish farming (GAP-FF).* Singapore, Singapore Food Agency (available at https://www.sfa.gov.sg/food-for-thought/article/detail/good-aquaculture-practice-for-fish-farming).

UNEP. 2010. *Clearing the waters: A focus on water quality solutions*. Nairobi, United Nations Environment Programme (available at https://sswm.info/sites/default/files/reference_attachments/UNEP%20 2010%20Clearing%20the%20Waters.pdf).

UNEP. 2016. *A Snapshot of the world's water quality: Towards a global assessment*. Nairobi, United Nations Environment Programme (available at https://uneplive.unep.org/media/docs/assessments/unep_wwqa_report_web.pdf).

UNEP. 2018. *A framework for freshwater ecosystem management. Volume 4: Scientific background*. Nairobi, United Nations Environment Programme (available at https://wedocs.unep.org/handle/20.500.11822/26031).

UN Water. 2016. *Towards a worldwide assessment of freshwater quality: A UN water analytical brief*. Geneva (available at https://www.unwater.org/publications/towards-worldwide-assessment-freshwater-quality).

USEPA. 2000. *Nutrient criteria technical guidance manual: Rivers and streams*. Washington, DC, Environmental Protection Agency (available at www.epa.gov/sites/production/files/2018-10/documents/nutrient-criteria-manual-rivers-streams.pdf).

USEPA. 2008. *Nutrient criteria technical guidance manual: Wetlands*. Washington, DC, Environmental Protection Agency www.epa.gov/sites/production/files/2018-10/documents/nutrient-criteria-manual-wetlands.pdf).

USEPA. 2022. *National recommended water quality criteria: Aquatic life criteria table.* Washington, DC, Environmental Protection Agency (available at www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table).

USEPA. 2021. Supplemental Module: Aquatic Life Criteria Washington, DC, Environmental Protection Agency (available at https://www.epa.gov/wqs-tech/supplemental-module-aquatic-life-criteria#tab-2)

Wang, M., Zhang, D., Dong, J. & Tan, S.K. 2018. Application of constructed wetlands for treating agricultural runoff and agro-industrial wastewater: A review. *Hydrobiologia*, 805: 1–31. https://doi.org/10.1007/s10750-017-3315-z.

Wurtsbaugh, W., Paerl, H. & Dodds, W. 2019. Nutrients, eutrophication and harmful algal blooms along the freshwater to marine continuum. *Wiley Interdisciplinary Reviews: Water*, 6(5). https://doi.org/10.1002/wat2.1373.