Food and Agriculture
Organization of the
United Nations

International Water
Management Institute

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

Required citation:
Drechsel, P., Marjani Zadeh, S. & Pedrero, F. (eds). 2023. *Water quality in agriculture: Risks and risk mitigation.* Rome, FAO & IWMI. https://doi.org/10.4060/cc7340en

ISBN 978-92-5-138072-7

Cover illustration and Graphic design : Yildiz Eviren

Chapter 4

Risk analysis and risk mitigation approaches: Waterborne pathogens that become foodborne pathogens through irrigation

Ana Allende and Pay Drechsel

Agricultural water is used extensively during produce-growing activities (e.g. irrigation, fertilization, frost protection, pesticides application), harvesting, marketing (e.g. rinsing) and cooling (e.g. hydrocooling). Scientific evidence points to agricultural water as a major risk factor in the contamination of fresh produce (European Commission, 2017). FAO (1995) and WHO (2006) have provided evidence that pathogenic microorganisms represent the single-most important health risk for food safety where any form of water contaminated by domestic wastewater is used for irrigation or in post-harvest food handling. This water can be contaminated through a variety of pathways and can potentially spread bacteria, viruses (see Box 4.1) and parasites to crops, humans and animals.

Box 4.1. COVID-19

Many research groups have successfully detected macromolecules (ribonucleic acid or the RNA) of the SARS-CoV-2 virus in wastewater, which can then be used to monitor COVID-19 in a community (Kitajima *et al.*, 2020). However, the COVID-19 virus is an enveloped virus, which is less stable in the environment and more susceptible to oxidants, such as chlorine, than other types of viruses such as enteroviruses (La Rosa *et al.*, 2020). As a result, the presence of infectious SARS-CoV-2 viruses in treated or untreated wastewater has not been demonstrated, making the risk of a faecal-oral transmission of SARS-CoV-2 via contaminated drinking water or irrigated food low. It has also been suggested that conventional wastewater treatment is adequate to control the transmission of COVID-19, as RNA fragments of SARS-CoV-2 have not been detected in fully treated sewage (WHO & UNICEF 2020).

Practical observations indicate that farmers use the water they have available. However, water availability and quality differ from one context to another, and may be fit to use only for certain purposes. Establishing fit-for-purpose water use requires assessment of the water source, analysis of the treatment options to ensure appropriate quality for end use and evaluation of multiple barrier processes (Neale *et al.*, 2020). The end use of the food product (e.g. if eaten raw) must be also considered (FAO & WHO, 2019).

To guarantee not only the suitability of the water, but also the sustainability of the system, it is important to establish the minimum requirements according to the "fit-for-purpose" approach, which necessitates setting water-quality goals in relation to end user needs (Helmecke, Fries & Schulte, 2020).

Current good agricultural practices (GAP) should include practical knowledge adequate to enable growers to predict potential contamination outcomes, identify suitable preventive measures and prioritize risk management efforts. These activities should be integrated into risk analysis and risk mitigation approaches, as already reflected in several guidelines for water reuse, such as the World Health Organization (WHO) Health Guidelines for the Use of Wastewater in Aquaculture and Agriculture and the ISO Guidelines (16075) for Treated Wastewater Use for Irrigation (Helmecke, Fries & Schulte, 2020).

4.1. Potential microbiological risks and corrective actions

While a variety of water sources are available for field operations and irrigation, extensive knowledge is needed to relate risk factors associated with the transfer coefficients for pathogens by source, concentration and use (CPS, 2014). Of utmost importance is the selection of the water source as well as the intended use of the water to ensure that irrigation water does not represent a potential source of contamination. When irrigation water is contaminated, the main route of exposure to microbial hazards is ingestion, including the consumption of irrigated crops and the ingestion of droplets produced by sprays (EPHC, NRMMC & AHMC, 2006).

Table 4.1 summarizes the main occupational and consumption-based human health risks from irrigating vegetables with polluted water. Although some respiratory and skin illness can be also attributed to pathogenic microorganisms present in contaminated water, there is a lack of information about their significance, compared with consumption-related risks, which can reach a much larger community if the vegetables are intended for sale.

Table 4.1. Main human health risks from irrigating vegetables with polluted water

Type of risk	Health risk	Group at risk	Exposure pathway
Occupational risks (contact)	• Parasitic worm (helminth) infections with for example roundworms (e.g. Ascaris) via ingestion of worm eggs or though larvae penetrating the skin (e.g. hookworms) • Diarrhoeal diseases, especially in children, linked to enteric viruses • Skin infections causing itching and blisters on hands and feet, but also dermatitis (eczema).	• Farmers/field workers • Children playing on the farm	• Hand or fingers (in contact with contaminated water and soil) put in the mouth • Larvae enter the skin of individuals working barefoot
		• Traders and market vendors • Kitchen staff or household members engaged in food preparation	• Hand or fingers in contact with contaminated crops put in the mouth, incl. vegetables washed on-farm or in markets with unsafe water
Consumption-related risks (food chain)	• Bacterial and viral infections such as typhoid, hepatitis A, viral enteritis which mainly cause diarrhoea, but also e.g., cholera. • Parasitic worms such as *Ascaris*	• Consumers at home or of street food • Farmers or children eating on the farm	• Consumption of contaminated vegetables or fruits that have not been carefully peeled, washed, sanitized or cooked

Source: Modified from FAO. 2019. On-farm practices for the safe use of wastewater in urban and peri-urban horticulture: A training handbook for Farmer Field Schools. Second edition. Rome.

One of the main challenges facing growers is determining whether the quality of the available water source is suitable for the intended use. This requires understanding the potential microbiological risks linked to the agricultural water. Ascertaining whether the microbial quality of water is acceptable for different agricultural uses and how the agricultural practices, crop type and climatic conditions affect microbial quality is not an easy task (CPS, 2014). Many international guidelines and regulations require growers to take adequate measures, as appropriate, and to use potable or clean water, whenever necessary, to reduce the risk of microbial contamination of produce via water. However, instead of focusing on where potable water or other water quality types can be used, it is more productive to articulate an assessment of the water's fitness for the intended purpose (FAO & WHO, 2019). In fact, an increasing number of competent authorities support the establishment of risk management approaches based on risk and scientific evidence.

Once the potential risks have been identified and, where possible, the minimum microbial requirements established, it is important to understand which corrective actions need to be in place to ensure that potential microbial contaminants, if present in the water source, are eliminated. Suitable intervention strategies should be implemented by growers to reduce food safety risks in fresh produce. Table 4.2 summarizes the occupational risks and reduction measures and relevant considerations for end users.

Table 4.2. Occupational risk reduction

<table>
<tr><th>Kind of occupational risk</th><th>Risk reduction measures</th><th>Considerations</th></tr>
<tr><td>Hand contact with water or irrigated crops and soils, and possibility of hand-mouth contact (farmers, traders)</td><td>• Targeted risk reduction (hygiene promotion) programmes
• Use of gloves for crop handlers
• Availability of clean water for drinking and handwashing
• Frequent handwashing with soap, especially before eating in the field
• Chemotherapeutic control (de-worming medicine) especially for children playing on farm up to three times a year in endemic areas</td><td rowspan="2">Awareness raising about risks and good hygiene is important as

a) not all farmers or traders are aware that the used irrigation water is unsafe from a pathogenic perspective

b) protective clothing has a cost factor and can limit mobility and comfort in (hot) tropical climates, and its adoption requires support. Monitoring of farmer compliance with health directives might work in some regions, while in others incentive systems (e.g. "best urban farmer or farming community") could encourage compliance.</td></tr>
<tr><td>Contact with water and soils via feet and legs</td><td>• Targeted risk reduction (hygiene promotion) programmes
• Avoiding walking into streams or ponds to fetch water
• Use of irrigation systems which minimize water-body contact
• Use of sandals, shoes or ideally boots by field workers
• Frequent body (leg and feet, hand) washing with soap
• Chemotherapeutic control (de-worming medicine) for farm workers if feasible</td></tr>
</table>

Source: Authors' own elaboration.

4.2. Overview of risk analysis frameworks

Current approaches require growers to develop and implement safety management systems and to perform risk assessments on irrigation water sources throughout the crop production cycle (i.e. field history, water sources, animal manures and worker hygiene to reduce microbial risks) (Allende & Monaghan, 2015). The WHO Health Guidelines for the Use of Wastewater in Aquaculture and Agriculture replace the standard approach used for water quality testing for faecal coliforms with a risk assessment/risk management-based approach that involves more flexible guidelines based on attributable risks and disability adjusted life years (De Keuckelaere *et al.*, 2015; WHO, 2006). However, the term "risk assessment" when used by growers usually refers to a general and qualitative approach based more on expert opinion and experience, as required by Good Agricultural Practices (GAP), than full implementation of a risk analysis (Monaghan *et al.*, 2017).

The Codex Alimentarius, also known as the "Food Code", is a collection of standards, guidelines and codes of practice adopted by the Codex Alimentarius Commission (CAC), which forms the central part of the Joint FAO/WHO Food Standards Programme. The CAC recognize that water can be an important source of contamination of food, and have recently issued a call through the Codex Committee on Food Hygiene (CCFH) for the safe use of water in food production, with a particular focus on primary production of fresh produce. The report of a joint FAO/WHO expert meeting, entitled "Safety and Quality of Water Used in Food Production and Processing" (otherwise known as the JEMRA report) (FAO & WHO, 2019) represents a first attempt to implement such a broad approach. In recent years, most Codex documents as well as legislative proposals have highlighted the need to implement a risk-based approach for safe water reuse, and indicated the need to perform assessments to determine fitness for specific water uses. An increasing number of recent research studies have also focused on evaluating the microbial quality of irrigation water used for the production of fresh produce and its significance as a source of contamination.

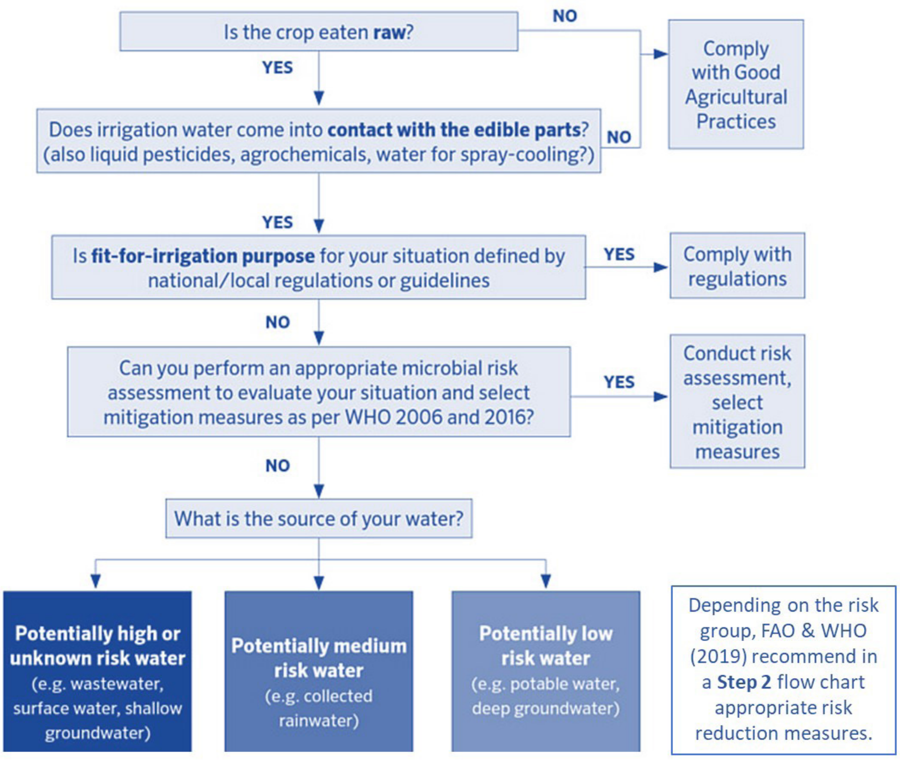
Agricultural water risk assessments rely on data from microbiological analysis, epidemiological studies and/or quantitative microbial risk assessment (QMRA) (Bos, Carr & Keraita, 2010). In most cases, QMRA is applied to establish links between concentrations of pathogenic microorganisms in agricultural water and the probability of illness. However, it should be noted that farmers in most countries where water quality guidelines are of relevance do not have access to QMRA data. For this reason, many guidelines and quality standards provide growers with directions on the minimum factors to be considered when assessing the risk of their pre-harvest agricultural water systems. Four principal steps should be included in the risk assessment: 1) identification of potential hazards that may be present in the agricultural water source; 2) the water delivery system; 3) the application method, and 4) the intended use of the crop.

Risk analysis is usually performed using Decision Support Systems (DSS). Such systems help farmers – and everyone else who makes decisions - to select the best solution during the decision-making process. In this respect, several approaches have been applied to ensure water is of appropriate quality for its intended use. In primary agricultural production, DSS provides growers with a tool to perform risk assessments of water used based on a combination of information related to the water source, the irrigation method, the type of crop and consequently potential contact with the edible portion of the crop (European Commission, 2017).

On-farm, qualitative, risk-based approaches based on DSS usually rely on the development of decision trees (DTs). These useful tools help growers make decisions on the risk level and choice of water source with the aim of avoiding the introduction of hazards that compromise food safety. Many GAP guidelines already include DTs to help growers characterize the water source, identify potential risks, establish the intended use and identify suitable microbial metrics to be applied to irrigation water (FAO & WHO, 2019). Most of the proposed DTs include actions that can be taken on the farm to reduce risks of contamination from agricultural water used during production. For example, the European Commission (2017) guidance document on addressing microbiological risks in fresh fruit and vegetables through good hygiene includes a matrix to support risk assessment of agricultural water based on the combination of water source, irrigation method and potential contact with the crop and commodity type.

The ISO 16075 contains guidelines for the development and execution of projects intending to use treated wastewater (TWW) for irrigation, and considers the parameters of climate and soil. This guidelines classify the TWW based on different quality levels, which are characterized by levels of specific contaminants and further correlated to the various potential uses (ISO 16075-2) (ISO, 2020). Figure 4.1 shows an example of a decision tree that could be used to identify main risk groups linked to the potential contamination of irrigation water as well as critical questions to be asked to enter the second step of the decision tree.

Figure 4.1. Step 1 (Context analysis) of a decision tree for microbiological risk assessments.



Source: Adapted from FAO & WHO. 2019. Safety and quality of water used in food production and processing – Meeting report. Microbiological Risk Assessment Series No. 33. Rome

Similar examples of decision trees have been developed by many international organizations. For instance, the European Commission (2017) guidance document contains similar questions and includes a limited number of sampling recommendations. For a comparison of the strengths and limitations of tools for the assessment of faecal pathways and related risks in the larger urban environement, see Mills *et al.* (2018).

4.3. Available risk mitigation measures

In primary production, the quality of water sources can vary widely both over the short term and the long term, as in the case of surface water (e.g. river, canals). This variation reduces the usability of water monitoring as a risk management tool and triggers the need for fit-for-purpose risk mitigation measures that are commensurate with the variations observed.

QMRA can be used as a tool to assess the impact of different risk mitigation strategies (De Keuckelaere *et al.*, 2015). During studies, it enables the evaluation of scenarios that correspond to the implementation of different intervention strategies. The results provide information on the relative impact of the selected strategies on the contamination of the product. However, as noted earlier, farmers in most countries where water quality guidelines are relevant, lack access to QMRA data. In such cases, the DT approach for the selection of risk mitigation measures is one of the best options.

In the JEMRA report (FAO & WHO, 2019), a DT with a binary (Yes/No) structure is developed to aid in the selection of risk reduction measures for produce. The DT applies a multiple-barrier approach to identify all points where pathogen loads could be increased through the use of poor quality water, as well as to identify intervention strategies that could reduce the contamination of fresh produce. The DT then recommends different preventive measures based on the classification of risk for the water source use by the grower. The preventive measures suggested by FAO & WHO (2019) include the selection of different irrigation systems of lower risk as well as the search for alternative water sources.

The identification and implementation of preventive measures should be based on the multiple barrier principle. According to this principle, multiple preventive measures or barriers are used to control the risks posed by different hazards, thus making the process more reliable. The strength of this principle is that a failure of one barrier may be compensated by the remaining barriers, thus minimizing the likelihood of contaminants passing through the entire system and being present in sufficient amount to cause harm to human health or environmental matrices (Alcalde-Sanz and Gawlik, 2017).

As previously stated by WHO (2011), many control measures may contribute to controlling more than a single hazard, whereas some hazards may require more than a single control measure. This approach has been covered in previous reports and books such as the 2019 meeting report published by FAO and WHO (2019) on the safety and quality of water used in food production and processing, and a publication by Drechsel *et al.* (2010) entitled Wastewater Irrigation and Health. Based on these directives, it is clear that the critical control point concept is similar to the multiple-barrier approach. They conclude that while each individual barrier may not be able to completely remove or prevent contamination, and therefore protect public health, implemented together, the barriers work to provide greater assurance that the water or food will be safe at the point of consumption (Amoah *et al.*, 2011). Case study 1 in the annex describes the research carried out in Ghana where different barriers were tested.

WHO (2016) summarized exposure reductions provided by on-site preventive measures for water safety management and included most of the control measures previously suggested by NRMMC (2006) and WHO (2006). FAO & WHO (2019) addressed qualitative effectiveness of selected control measures for produce, with a focus on small-scale production contexts. The options for risk reduction measurements offer a good overview of the alternatives that could be selected by the grower and the possible effectiveness ratings of water application and treatments (reduction of microorganism levels). In the discussion paper "Options for Updating the 2006 WHO Guidelines", Mara *et al.* (2010) reviewed all the available control measures in the pre-harvest (on-farm) and postharvest contexts. Tables 4.3 and 4.4. summarize the majority of reduction measurements proposed by previous guidelines and reports.

Table 4.3. Risk reduction measures for irrigated food crops

Control measure	Effectiveness (reduction in logs)	Considerations
Use of alternative low-risk water source (e.g., deep well)	5	Depends on groundwater availability, quality, and land tenure secirity to invest e.g. in well drilling
Water treatment options: - Conventional wastewater treatment - Three-tank system on farm - Simple sedimentation pond on farm - Simple water filtration on farm	 1-7 1-2 0.5-1 1-3	 Inactivation of pathogen will depend on type and sophistication of the treatment selected. For conventional treatment systems, see Table 5.2 in WHO (2006)
Crop restrictions (no crops allowed with edible parts eaten raw)	6-7	Inactivation of pathogens will depend on the effectiveness of local enforcement of crop restriction, especially where farmers will face lower income by using alternative crops
Irrigation related options: - Furrow irrigation system - Surface drip irrigation system - Sub-surface drip system - Reduction of soil splashing on leaves	 1-2 2-4 6 1-2	 Pathogen reduction will increase from low- to high-growing crops Use of a rose for watering cans in overhead irrigation
Natural pathogen die-off under dry and ideally hot conditions (assuming no recontamination during handling)	0.5-2 per day	Rate depends on the weather and time interval between the last irrigation event and harvest up to consumption
Postharvest measures (e.g. in markets): - Overnight storage in baskets - Crop preparation (removal of outer, external leaves) - Washing in a bowl - Washing under running tap water	 0.5-1 1-3 1-2 2-3	 Well aerated Cabbage, lettuce Depends on washing duration (min. 1-2 min) and frequency of water change Depends on washing duration (min. 1-2 min)
Kitchen-based processes: - Peeling - Disinfection (5 min) and rinsing with water - Washing 2 min in salt solution - Washing 5 min in a vinegar solution - Cooking	 2 2-3 1-2 2-4 5-7	 Fruits, root crops For example, with permitted chlorine tablets or solutions Effectiveness increases with salt concentration Effectiveness increases with vinegar concentration Option depends on local diets/preferences

Sources: Mara, D., Hamilton, A., Sleigh, A. & Karavarsamis, N. 2010. Discussion paper: Options for updating the 2006 WHO guidelines. WHO, FAO, IDRC, IWMI; Amoah, P., Keraita, B., Akple, M., Drechsel, P., Abaidoo, R.C. & Konradsen, F. 2011. Low-cost options for reducing consumer health risks from farm to fork where crops are irrigated with polluted water in West Africa. IWMI Research Report Series 141, Colombo; FAO & WHO. 2019. Safety and quality of water used in food production and processing – meeting report. Microbiological Risk Assessment Series No. 33. Rome; ISO. 2020. Guidelines for treated wastewater use for irrigation projects. ISO 16075-2. Geneva, International Organization for Standardization. NRMMC. 2006. Australian guidelines for water recycling: Managing health and environmental risks (phase 1). Canberra

Log reductions of pathogens are well defined for most control measures, including water treatment. However, research studies focused on primary production have generated new scientific evidence that enables better understanding of the impact of different preventive measures. For example, a published paper by Belias *et al.* (2020) suggests that the use of a single die-off rate (0.5 log/day) for estimating time-to-harvest intervals across different weather conditions, produce types and bacteria should be reviewed. The study concludes that the rate of die-off appears to be impacted by produce variety, bacteria and weather. As such, the proposed use of the die-off principle (0.5 log/day) as an intervention for contaminated water should be revised to take these factors into account. The reduction attributable to risk mitigation strategies also needs to be updated. However, there is lack of scientific evidence on the performance efficacy of most preventive measurements, including potential synergies. There are many, "average" efficiencies relating to different processes for the removal or inactivation of microorganisms with wide ranges of effectiveness (FAO & WHO, 2019). More research is therefore needed to understand pathogen reduction efficiencies and the performance variation of treatments. Another, and likely much larger challenge relates to the adoption of the recommended risk reduction practices where risk awareness is low and incentives are needed to support behaviour change (Drechsel, Qadir & Galibourg, 2022).

Table 4.4. Comparison of the qualitative effectiveness of selected control measures for produce in the postharvest context

Control measure	WHO (2006)	Mara *et al.* (2010)	WHO (2016)	FAO & WHO (2019)	ISO (2020)
Washing in water	1-2			*	1
Washing in disinfectant	1-2	2-3		**	2
Peeling	2	2	2	**	2
Cooking	5-6	5-6	5-6	*****	6-7

Source: Authors' own elaboration

One of the most plausible solutions for growers faced with the uncertainty of agricultural water quality, like the repeated failure of the only available water source to meet the metrics for indicator bacteria, is the use of water treatments at their end through chlorine injections (Suslow, 2010). In 2015, Allende and Monaghan summarized the most commonly applied water treatments for agricultural water. They reviewed physical and chemical disinfection systems as methods to remove human pathogens from agricultural water sources, although disinfection treatment of irrigation water remains a very limited practice. Nowadays, chemical sanitizers are the most commonly used water treatments, although environmentally friendly alternatives are being demanded, particularly for organic production. In fact, concerns have risen recently regarding both the absence of water treatment and the excessive use of potentially toxic disinfection by-products that accumulate in irrigation water.

Based on Tables 4.3. and 4.4, the most effective single risk barriers where irrigation water is likely polluted remain crop restrictions, drip irrigation, and produce cooking. In the common situation that (i) farmers might not agree with crop restrictions, (ii) drip kits are costly and require more land use security than many informal urban farmers have, and last but not least (iii) post-harvest produce (re)contamination is possible, food safety can eventually only be assured through measures close to consumption, like produce disinfection and washing, or cooking. The high risk of produce contamination along the marketing chain low-income countries is a strong argument for WHO's (2006) shift to health-based targets instead of relying on irrigation water standards.

References

Alcalde-Sanz, L. & Gawlik, B.M. 2017. *Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge—towards a legal instrument on water reuse at EU level*, EUR 28962 EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-79-77175-0.

Allende, A. & Monaghan, J. 2015. Irrigation water quality for leafy crops: A perspective of risks and potential solutions. *International Journal of Environmental Research and Public Health*, 12, 7457–7477.

Amoah, P., Keraita, B., Akple, M., Drechsel, P., Abaidoo, R.C. & Konradsen, F. 2011. *Low-cost options for reducing consumer health risks from farm to fork where crops are irrigated with polluted water in West Africa*. IWMI Research Report Series 141, Colombo (available at www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB141/RR141.pdf)

Belias, A.M., Sbodio, A., Truchado, P., Weller, D., Pinzon, J., Skots, M., Allende, A., Munther, D., Suslow, T., Wiedmann, M. & Ivanek, R. 2020. Effect of weather on the die-off of *Escherichia coli* and attenuated *Salmonella Typhimurium* on preharvest baby lettuce and spinach following a simulated irrigation event with contaminated water in California, New York, and Spain. *Applied and Environmental Microbiology*, 86(17):e00899-20. DOI:10.1128/AEM.00899-20.

Bos, R., Carr, R. & Keraita, B. 2010. Assessing and mitigating wastewater-related health risks in low-income countries: An introduction. *In* P. Drechsel, C.A. Scott, L. Raschid-Sally, M. Redwood & A. Bahri, eds. *Wastewater irrigation and health: Assessing and mitigating risk in low-income countries*. Ottawa, International Development Research Centre (IDRC).

CPS. 2014. *Agricultural water: Five year research review.* Davis, CA, Center for Produce Safety.

De Keuckelaere, A., Jacxsens, L., Amoah, P., Medema, G., McClure, P., Jaykus, L-A. & Uyttendaele, M. 2015. Zero risk does not exist: Lessons learned from microbial risk assessment related to use of water and safety of fresh produce. *Comprehensive Reviews in Food Science and Food Safety*, 14, 387–410.

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

Drechsel, P., Scott, C.A., Raschid-Sally, L., Redwood, M. & Bahri, A. 2010. *Wastewater irrigation and health: Assessing and mitigating risk in low-income countries.* London, Earthscan-IWMI-IDRC.

European Commission. 2017. *European Commission Notice No. 2017/C 163/01 Guidance document on addressing microbiological risks in fresh fruit and vegetables at primary production through good hygiene*. Brussels, EC (available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017XC0523%2803%29).

EPHC, NRMMC & AHMC. 2006. *Australian guidelines for water recycling: Managing health and environmental risks (Phase 1).* Environment Protection and Heritage Council, Natural Resource Management Ministerial Council, Australian Health Ministers Conference (available at https://www.waterquality.gov.au/guidelines/recycled-water#managing-health-and-environmental-risks-phase-1).

FAO. 1995. *Water Quality for Agriculture*. Irrigation and Drainage Paper No. 29, Rev. 1. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2019. *On-farm practices for the safe use of wastewater in urban and peri-urban horticulture: A training handbook for Farmer Field Schools*. Second edition. Rome.

FAO & WHO. 2019. *Safety and quality of water used in food production and processing – meeting report.* Microbiological Risk Assessment Series No. 33. Rome.

Helmecke, M., Fries, E. & Schulte, C. 2020. Regulating water reuse for agricultural irrigation: Risks related to organic micro-contaminants. *Environmental Sciences Europe*, 32, 4.

ISO. 2020. *Guidelines for treated wastewater use for irrigation projects*. ISO 16075-2. Second edition. Geneva, International Organization for Standardization.

Kitajima, M., Ahmed, W., Bibby, K., Carducci, A., Gerba, C.P., Hamilton, K.A., Haramoto, E. & Rose, J.B. 2020. SARS-CoV-2 in wastewater: State of the knowledge and research needs. *Science of the Total Environment*, 739, 139076. https://doi.org/10.1016/j.scitotenv.2020.139076.

La Rosa, G., Bonadonna, L., Lucentini, L., Kenmoe, S. & Suffredini, E. 2020. Coronavirus in water environments: Occurrence, persistence and concentration methods – a scoping review. *Water Research*, 179, 115899 https://doi.org/10.1016/j.watres.2020.115899.

Mara, D., Hamilton, A., Sleigh, A. & Karavarsamis, N. 2010. *Discussion paper: Options for updating the 2006 WHO guidelines*. WHO, FAO, IDRC, IWMI. https://www.who.int/docs/default-source/wash-documents/wastewater-use/using-human-waste---kit-2/discussion-paper---options-for-updating-the-2006-who-guidelines.pdf

Mills, F.; Willetts, J.; Petterson, S.; Mitchell, C. & Norman, G. 2018**.** Faecal Pathogen Flows and Their Public Health Risks in Urban Environments: A Proposed Approach to Inform Sanitation Planning. *Int. J. Environ. Res. Public Health* 2018, 15, 181. https://doi.org/10.3390/ijerph15020181

Monaghan, J.M., Augustin, J.C., Bassett, J., Betts, R., Pourkomailian, B. & Zwietering, M.H. 2017. Risk assessment or assessment of risk? Developing an evidence-based approach for primary producers of leafy vegetables to assess and manage microbial risks. *Journal of Food Protection*, 80, 725–733.

Neale, M.R., Sharvelle, S., Arabi, M., Dozier, A. & Goemans, C. 2020. Assessing tradeoffs of strategies for urban water conservation and fit for purpose water. *Journal of Hydrology*, X, 8, 100059.

NRMMC. 2006. *Australian guidelines for water recycling: Managing health and environmental risks (phase 1)*. https://www.waterquality.gov.au/sites/default/files/documents/water-recycling-guidelines-full-21.pdf

Suslow, T.V. 2010. Standards for irrigation and foliar contact water. (available at http://www.pewtrusts.org/~/media/assets/2009/pspwatersuslow1pdf.pdf).

WHO. 2006. *Guidelines for the safe use of wastewater, excreta and greywater. Volume II: Wastewater use in agriculture*. Paris, WHO-UNEP-FAO (available at https://www.who.int/publications/i/item/9241546832).

WHO. 2011**.** Guidelines for drinking water quality (4th edition). Geneva, World Health Organization

WHO. 2016. *Quantitative microbial risk assessment: Application for water safety management*. Geneva, World Health Organization (available at https://apps.who.int/iris/handle/10665/246195).

WHO & UNICEF. 2020, 29 July. *Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19: Interim guidance*. Geneva, World Health Organization (available at https://apps.who.int/iris/handle/10665/333560. License: CC BY-NC-SA 3.0 IGO).