CHAPTER 8. ORGANIC MATTER, PATHOGENS AND EMERGING POLLUTANTS

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While crop production is the main agricultural activity contributing to global water pollution through the release of nutrients, pesticides, salts and sediments, livestock is the principal source of pollution by organic matter, pathogens, and emerging pollutants such as hormones and antibiotics.

Given the growing trends in livestock production (see Chapter 2), the current and predicted importance of pollutants such as zoonotic water-borne pathogens or organic matter, is probably out of the question. Nevertheless, in recent years, there have been growing concerns about new and emerging pollutants found in the aquatic environment. Such pollutants present a new water quality challenge in both developing and developed countries, due to their potential impacts on human and environmental health and the lack of regulations to monitor and control them.

This chapter provides a very brief analysis of the main agricultural sources of these pollutants and their main effects on water quality.

8.1 Organic matter

The main sources of agricultural water pollution by organic matter include livestock-related wastes such as animal excreta, uneaten animal feed, effluents from animal-processing industries and mismanaged crop residues.

Pollution by organic matter is typically measured by biological oxygen demand (BOD): the amount of oxygen used by microorganisms to decompose waste. Livestock-related wastes have the highest BOD levels (see Table 8.1). For example, the BOD of pig slurry is in the range of 30 000–80 000 milligrams per litre, as compared with the typical BOD of domestic sewage at 200–500 milligrams per litre (FAO, 2006).

As is the case for other pollutants, pollution by organic matter is growing because of increasing municipal and industrial wastewater discharge, the intensification of agriculture (including livestock farming) and reduction in river dilution capacity due to climate change and water extractions. Water pollution by organic matter from intensive livestock farming is now significantly more widespread than organic pollution from urban areas, affecting a larger extent of water bodies (Wen *et al.*, 2017). Global meat consumption nearly doubled between 1980 and 2004, with an annual increase of around 3.6% per year; it is expected to double again by 2030 (FAO, 2011). As a result of expected urbanization, further expansion and intensification of the livestock sector (see Chapter 2), and changes in river discharge, more rivers are predicted to be degraded by organic matter beyond acceptable limits. Figure 8.1 shows that by 2050 the world's worst water quality deterioration is projected to occur in India, sub-Saharan Africa and Mexico, with other smaller regions also facing substantial challenges. Pollution in China was the highest and most widespread in 2000 and will remain among the highest in 2050. The intensification of livestock farming is a key driver of water pollution in India, Africa and South America. By contrast, intensive livestock farming in Europe and China is expected

Table 8.1 | Ranges of BOD concentrations for various wastes and animal products

Source	BOD (mg/litre)
Milk	140 000
Silage effluents	30 000-80 000
Pig slurry	20 000-30 000
Cattle slurry	10 000-20 000
Liquid effluent draining from slurry stores	1 000-12 000
Untreated domestic sewage	200-500
Treated domestic sewage	20-60
Clean river water	5

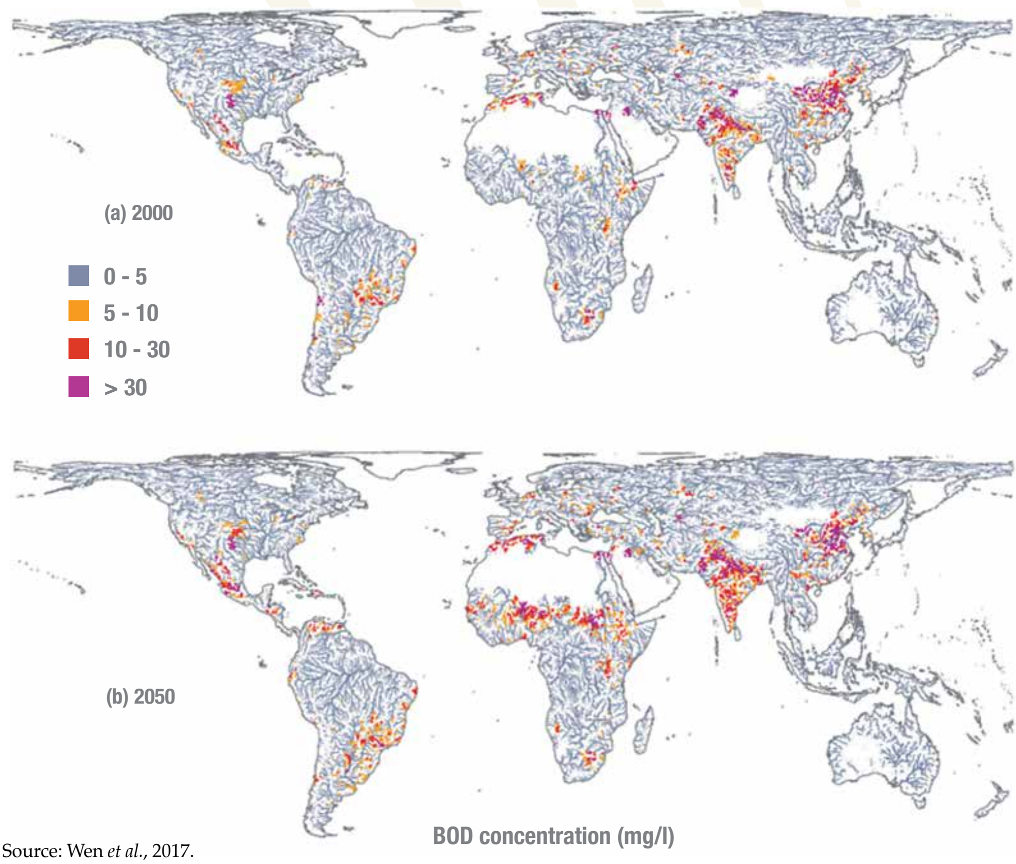
Source: adapted from FAO, 2006.

to stay constant or decline in the coming decades, which may reduce the pressure on very stressed river basins in these regions (Wen *et al.*, 2017).

Locally, aquaculture can be also a major contributor to organic loads in water. In Scotland, for example, the discharge of untreated organic waste from salmon production is equivalent to 75 percent of the pollution discharged by the human population. Shrimp aquaculture in Bangladesh generates 600 tonnes of waste per day (SACEP, 2014).

Organic matter consumes dissolved oxygen in water as it degrades, contributing strongly to hypoxia in water bodies (Malling *et al.*, 2006). The discharge of organic matter also increases the risk of eutrophication and algal blooms in lakes, reservoirs and coastal areas. The number of people thought to be potentially affected by organic pollution (BOD >5 mg/l) is projected to increase from 1.1 billion in 2000 to 2.5 billion in 2050, with developing countries disproportionately affected (Wen *et al.*, 2017). See Figure 8.1.

FIGURE 8.1 Global patterns of computed river BOD concentrations in the years 2000 and 2050



Source: Wen *et al.*, 2017.

8.2 Pathogens

Livestock excreta contain many zoonotic microorganisms and multicellular parasites, which can be harmful to human health. Pathogenic microorganisms can be water-borne or food-borne (the latter especially if the food has been irrigated with contaminated water or with untreated or partially-treated wastewater). Some pathogens can survive for days or weeks in animal faeces that have been discharged onto land and they may later contaminate water resources via runoff (FAO 2006; WHO 2012).

Pathogens from livestock that are detrimental to public health include bacteria such as *Campylobacter* spp., *Escherichia coli* O157:H7, *Salmonella* spp., *Clostridium botulinum* and parasitic protozoa such as *Giardia lamblia*, *Cryptosporidium parvum* and *Microsporidia* spp., all of which cause hundreds of thousands of infections every year (Christou, 2011).

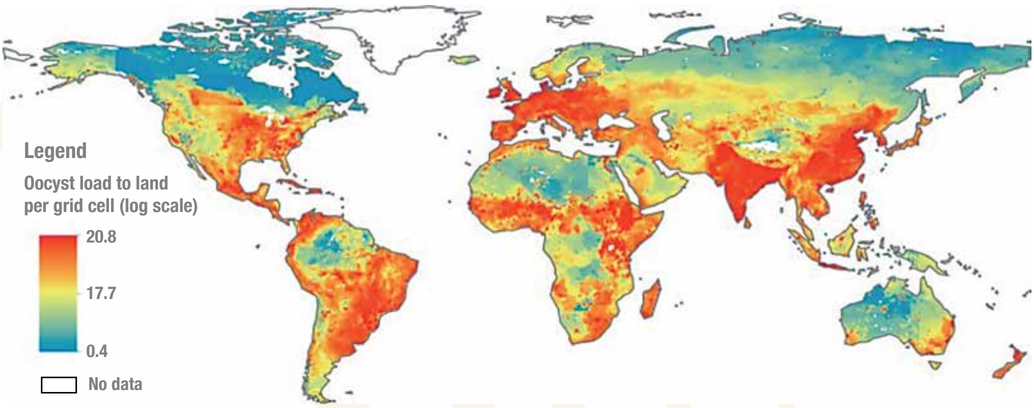
Domestic animals, such as poultry, cattle, sheep and pigs, generate 85% of the world's animals faecal waste, proportionally a far greater amount than is contributed by the world's human population. The faecal production rate and contribution to the environment by these animals can be as high as 2.62×10^{13}kg / year (WHO 2012).

Understanding and quantifying the loads, transport and fate of pathogens are challenging tasks because the environmental pathways are complex and observational data is very scarce (Atwill *et al.*, 2012, Ferguson and Kay, 2012). The risks associated with animal waste are episodic in nature, because of sporadic loads or transmissions (e.g. after rainy events). Further complexity is added by the extreme spatial and temporal variability of weather patterns and livestock management practices in different regions of the world. Therefore, the analysis of loads and environmental pathways, particularly at scales larger than local, are typically based on models.

Cryptosporidium has been proposed as a good indicator for modelling at the global scale as it is a widespread water-borne livestock pathogen that has relatively high incidence in child diarrhoea (Liu *et al.*, 2015). Vermeulen *et al.*, (2017) modelled the global loads of livestock Cryptosporidium, which they estimated to be 3.2×10^{23} oocysts per year. The study showed that cattle, especially calves, are the largest contributors to oocyst loads, followed by chickens and pigs. Spatial differences (see Figure 8.2) are linked to animal distributions. North America, Europe and Oceania together account for nearly a quarter of the total oocyst load, meaning that the developing country regions account for the largest share.

The human risks associated with pathogen pollution of water from livestock have not yet been well defined (WHO, 2012) but they are potentially high, given the number of

FIGURE 8.2 **Global oocyst load from livestock to land (E) per grid cell per year**



Source: Vermeulen *et al.*, 2017.

outbreaks of infections with zoonotic pathogens that have been reported and documented among swimmers and other water users (Dufour *et al.*, 2012, McBride *et al.*, 2012). For example, in one outbreak in Swaziland, cattle manure was thought to have caused more than 40 000 cases of water-borne infections (Effler *et al.*, 2001). A more recent example is the 2016 outbreak of gastroenteritis on the North Island of New Zealand, which was attributed to the ingestion of water polluted by livestock faeces. Thousands of people were infected (Reiff, 2016).

Agricultural irrigation with untreated or partially-treated wastewater may result in the pollution by human pathogens, particularly in shallow groundwater aquifers. In the majority of low income countries, where most domestic and municipal wastewater goes untreated, alternative approaches are necessary to prevent pathogens from entering agricultural food production chains through wastewater irrigation. The WHO guidelines for the safe use of wastewater, excreta and greywater in agriculture (WHO, 2006) and the wastewater quality guidelines for agricultural use developed by FAO (1985; 1992) provide regulatory recommendations on the suitability of water for irrigation and identify possible restrictions in use.

8.3 Emerging pollutants

Emerging pollutants comprise a wide range of chemicals, substances and microbial pollutants that enter water bodies from various sources, including municipal wastewater treatment plants, agricultural runoff and industrial effluents. Emerging pollutants are also collectively referred to as '*emerging contaminants*' or '*contaminants of emerging concern*'.

Emerging pollutants are broadly grouped into pharmaceuticals, personal care products, pesticides, and industrial and household chemicals. Diverse types are present in highly variable concentrations in freshwater resources such as rivers, streams lakes and groundwater. Currently, more than 700 emerging pollutants, their metabolites and transformation products, are listed as being present in the European aquatic environment (NORMAN, 2016). Nevertheless, they are rarely controlled or monitored and further research is needed to assess their impacts on human health and the environment (UNESCO, 2015b). The potential human health risks of emerging pollutants through exposure to drinking water or agricultural products is a concern (UNESCO, 2011).

Pharmaceuticals are one of the largest groups of emerging pollutants detected in water bodies. For the most part, they are excreted by humans and animals, reaching the water through the means described above. A recent study by UNESCO and HELCOM (UNESCO, 2017) found the presence of 58 different pharmaceuticals (out of 111 monitored) in rivers in the Baltic Sea region. The study reported average concentrations of less than 0.1 μg/l for top 20 pharmaceuticals in river water samples; the highest concentrations exceeded 1.0 μg/l for twelve compounds (UNESCO, 2017). The World Health Organization also has reported the presence of pharmaceuticals used for human and veterinary therapeutic and diagnostic purposes at trace levels in the range of nanograms to low micrograms per litre in surface and groundwater resources (typically less than 0.1 μg/l or 100 ng/l) (WHO, 2011).

Many emerging pollutants are known to interfere with hormone biosynthesis and metabolism in humans and animals and therefore are commonly referred to as 'endocrine-disrupting compounds' (EDCs) (Diamanti-Kandarakis *et al.*, 2009). Endocrine-disrupting compounds include natural and synthetic hormones (such as estrogen), pharmaceuticals with hormonal side effects (ibuprofen, diclofenac, etc.), organochlorinated pesticides and industrial chemicals, plastics and plasticizers, fuels, and many other chemicals that are widely used in household or personal care products.

As noted above, emerging pollutants are released into the aquatic environment from a wide range of sources. Agriculture is a major source of some types of emerging pollutants. The main classes of emerging pollutants arising from agriculture and their potential routes of agricultural releases into surface waters are summarized in Table 8.1 (Boxall, 2012). These pollutants contaminate soil, groundwater and surface water through leaching and/or runoff from agricultural fields and livestock breeding facilities.

A dominant source of emerging pollutants released from agriculture into water arises from the veterinary use of medicines and hormones in aquaculture and veterinary practices. The overuse of veterinary medicines, such as antibiotics and artificial growth hormones in industrial farming, results in the release of their residues into soil, groundwater and surface waters through leakage from animal waste storage and disposal tanks and the use of animal manure as a fertilizer. Furthermore, the excessive use of antibiotics in agriculture, farming and aquaculture contributes to the development of antimicrobial-resistant bacteria and the presence of these bacteria in water bodies (see Box 8.1). For example, some studies suggest that manure from antibiotic-treated pigs enhances the spread of antibiotic resistance in soil bacterial communities (Heuer and Schmalla, 2007), whereas filtered water from agricultural drains reduced the abundance of aquatic resistant bacteria in a shallow coastal lake (Schallenberg and Armstrong, 2004). The UNESCO and HELCOM study cited above (UNESCO, 2017) also pointed out the lack of data on the sale and consumption of veterinary pharmaceuticals, and their sources, pathways and loading onto soils, surface and groundwater systems and the

BOX 8.1 | Antimicrobial resistant microorganisms and the role of agriculture

Large amounts of antibacterial compounds (ACs) are used across the globe to treat animals. These substances and antibacterial-resistant microbes can be released to the environment during the manufacturing process as well as through the release of animal excreta and the disposal of medical waste. Consequently, a wide range of antibacterial compounds has been detected in surface waters, groundwaters, soils and sediments in different geographical regions (Monteiro and Boxall, 2010) and elevated levels of antibacterial-resistant bacteria and markers for these have been detected in soils and surface waters impacted by human activities.

There is growing evidence that the presence of antibacterial compounds and antibacterial resistant genes (ARGs) in the natural environment indirectly affects human health and contributes to the global antibacterial resistance problem (Wellington *et al.*, 2013), which is predicted to result in millions of deaths by 2050. Once in the environment, these contaminants may persist or dissipate and will be distributed around the different environmental compartments: air, water, sediment, and biota. ACs and other chemical pollutants may also select for resistance in the environment. Humans can then be exposed to the ACs and ARGs through the breathing of dust; consumption of contaminated drinking water, plants, meat, fish and shellfish; recreational and bathing activities; and contact with wildlife. The level of exposure will be driven by a range of socio-economic, health and environmental drivers.

There is an urgent need to manage the loads and the environmental exposure to these contaminants within the agricultural sector and international organizations are already taking action to address this emerging and potentially critical issue (FAO, 2016).

aquatic environment (including agriculture and aquaculture). The study stressed the need to fill this data gap and noted that even the very scarce data available on the sale and consumption of veterinary pharmaceuticals indicate that the annual turnover can be comparable to the amount used in human medicine. Given the extent and continued growth of the livestock sector, and taking into account that animal manure is commonly applied onto the agricultural lands as fertilizer, agriculture could be a significant pathway for medical compounds to reach the aquatic environment in all regions of the world.

Agriculture may become one of the predominant sources of nanomaterials in the aquatic environment, with the use of engineered nanopesticides and nanomedicine in agriculture in the future.

Table 8.2 I Routes of emerging pollutants to surface waters and their importance compared to other sources

Emerging pollutant class	Route of input from agricultural systems	Other sources and routes to the environment	Relative importance of agricultural sources in terms of water contamination
Natural toxins	Release from plants, algae and fungi	N/A	High
Veterinary medicine	Excretion to soils by animals at pasture; application of contaminated manure and slurry to land	Manufacturing releases; disposal of containers	High
Hormones	Excretion of natural and synthetic hormones by animals at pasture; application of manure and slurry to land	Discharge of sewage sludge, containing natural and synthetic hormones from the human population	High – hormonal substances arising from animals Low – hormonal substances arising from the human population
Transformation products (TPs)	Produced from human-induced chemicals that are applied directly to agricultural systems or in activated sludge/irrigation water	Formed in wastewater treatment processes	Depends on the nature of the parent compound; High – TPs of veterinary medicines Low – TPs of pharmaceuticals, personal care products
Nanomaterials	Excretion of nanomedicines by livestock; application of sewage sludge to agricultural land as a fertilizer; irrigation with wastewater or contaminated surface water	Emissions from wastewater treatment plants; disposal of waste to landfill; manufacturing releases	Currently low, as nanomaterials are mainly used in personal care products and paints and coatings Importance could increase in the future as nanopesticide and nanomedicine markets develop

Emerging pollutant class	Route of input from agricultural systems	Other sources and routes to the environment	Relative importance of agricultural sources in terms of water contamination
Bioterrorism/ sabotage agents	Sabotage of crops and livestock	Chemical incidents in cities	Has the potential to be high (depending on the agent)
Human personal care products	Application of sewage sludge to agricultural land as a fertilizer; irrigation with wastewater or contaminated surface water	Emissions to surface waters from wastewater treatment plants	Low
Emerging persistent organic pollutants (e.g. flame retardants)	Application of sewage sludge to agricultural land as a fertilizer; irrigation with wastewater or contaminated surface water	Emissions to surface waters from wastewater treatment plants	Low
Human medicines	Application of sewage sludge to agricultural land as a fertilizer; irrigation with wastewater or contaminated surface water	Emissions from wastewater treatment plants; disposal of unused medicines to landfills; manufacturing releases	Low

Source: adapted from Boxall, 2012.

Agriculture is not only a source of emerging pollutants, it also contributes to the spread and introduction of these pollutants into aquatic environments through wastewater (re) use for irrigation and the application of municipal biosolids onto the land as fertilizers (Bolong *et al.*, 2009; Munoz *et al.*, 2009).

An estimated 35.9 million hectares of agricultural lands are subjected to the indirect use of wastewater (Thebo *et al.*, 2017). The potential long-term effects of emerging pollutants on human health and ecosystems as a result of wastewater use are not yet known (UNESCO, 2015b). The occurrence of a wide range of emerging pollutants in wastewater used for irrigation presents not only potentially-serious risks to human health and food safety through contaminated crops, but also spreads these pollutants to the aquatic environment and soil.

A UNESCO (2018) case study in the Oued Souhil area in Nabeul, Tunisia, indicated the occurrence of emerging contaminants in irrigation water – both in wastewater used for irrigation and in groundwater – as well as in soil. As the use of raw, insufficiently treated or reclaimed wastewater in agricultural irrigation continues to grow, concerns about emerging pollutants is highly significant since most of these pollutants are not adequately removed during conventional wastewater treatment. Advanced wastewater treatment technologies, (membrane/nano/ultra-filtrations, and reverse osmosis) partially remove some chemicals and pharmaceutically active compounds (Gonzalez *et al.*, 2016). For example, the removal rate of pharmaceuticals during wastewater treatment in secondary and tertiary wastewater treatment plants in the Baltic Sea region were reported at lower than 50% for nearly half of the 118 compounds monitored; only nine were removed with an efficiency higher than 95% (UNESCO, 2017).

The use of biosolids may also lead to the contamination of human food crops and animal feed through the soil as a mediating compartment (Carballa *et al.*, 2007). Pollutants known as endochrine disrupting chemicals (EDCs) have been found to be present in wastewater sludge (Barnabé *et al.*, 2009).

The effects and risks of individual pollutants on aquatic organisms have been studied to a certain extent, whereas potential effects on human health have been evaluated only marginally. Cumulative effects of a mixture of different types of pollutants on human health and ecosystems have not been studied at all (UNESCO, 2011). Several research suggest that endocrine disruptors affect fertility and reproductive health and cause birth defects and developmental disorders, whereas other pollutants may cause cancerous tumours and the development of bacterial pathogen resistance (including multi-persistence) in humans and animals even at low concentrations (Poongothai *et al.*, 2007).

The current scientific understanding on the fate and transport of emerging pollutants and their accumulation in the environment is sadly limited. They behaviour of these pollutants will differ depending on the compartment in which they are found in the environment (e.g., groundwater, surface water and sediment), due to different transformations that may take place, such as the production of by-products (metabolites and transformation products) with different ecotoxicological effects. The by-products of some pollutants are often more persistent than their parent compounds, exhibit greater toxicity and can mimic estrogenic properties (La Farré *et al.*, 2009). Research is needed to improve our understanding of the dynamics of these pollutants in water resources and the environment, and the methods needed to remove them from wastewater (UNESCO, 2015b). More research is also needed to assess the human health and environmental risks and effects of long-term exposure to emerging pollutants, as well as to evaluate their behaviour and accumulation in ecosystems.

There are also huge gaps in the existing regulatory and monitoring frameworks, as well as in data availability regarding the occurrence of emerging pollutants in wastewater and receiving water bodies (UNESCO, 2015b). Efforts to monitor, regulate and control emerging pollutants in water resources and wastewater is limited in both developed and developing countries (UNESCO, 2015a). Data on the presence of emerging water pollutants are very scarce (UNESCO, 2011). Regulations specifically addressing these pollutants are lacking at national and international levels. Emerging pollutants are not only a major challenge facing developing countries, where water quality and pollution control is poor due to inadequate regulatory frameworks and technical and human capacities. It is also a concern in developed countries – even if a country has achieved put in place effective agricultural pollution control measures – because most emerging pollutants are currently not regulated, routinely monitored and controlled.

8.4 References

Atwill, E., Li, X., Grace, D. & Gannon, V. 2012. Zoonotic waterborne pathogen loads in livestock. In WHO (World Health Organization). *Animal waste, water quality and human health*. Geneva.

Barnabé, S., Brar, S.K., Tyagi, R.D., Beauchesne, I. & Surampalli, R.Y. 2009. Pre-treatment and bioconversion of wastewater sludge to value-added products - fate of endocrine disrupting compounds. *Science of the Total Environment*, 407: 1471-1488.

Bolong, N., Ismail, A.F., Salim, M.R. & Matsuura, T. A review of the effects of emerging contaminants in wastewater and options for their removal. *Desalination*, 239: 229–246.

Boxall, A.B.A. 2012. New and emerging water pollutants arising from agriculture. Paris, OECD (Organisation for Economic Co-Operation and Development).

Carballa, M., Omil, F., Ternes, T. & Lema, J.M. 2007. Fate of pharmaceutical and personal care products (PPCPs) during anaerobic digestion of sewage sludge. *Water Research*, 41: 2139-2150.

Diamanti-Kandarakis, E., Bourguignon, J.P., Giudice, L.C., Hauser, R., Prins, G.S., Soto, A.M., Zoeller, R.T. & Gore, A.C. 2009. Endocrine-disrupting chemicals: an Endocrine Society Scientific Statement. *Endocrine Reviews*, 30(4): 293–342.

Dufour, A., Wade, T.J. & Kay, D. 2012. Epidemiological studies on swimmer health effects associated with potential exposure to zoonotic pathogens in bathing beach water – a review. *In* WHO. *Animal waste, water quality and human health*. Geneva.

Effler, E., Isaäcson, M., Arntzen, L., Heenan, R., Canter, P., Barrett, T., Lee, L., Mambo, C., Levine, W., Zaidi, A. & Griffin, P.M. 2001. Factors contributing to the emergence of Escherichia coli O157 in Africa. *Emerging Infectious Diseases*, 7(5): 812–819.

Heuer, H. & Smalla, K. 2007. Manure and sulfadiazine synergistically increased bacterial antibiotic resistance in soil over at least two months. *Environmental Microbiology*, 9(3): 657-666.

FAO (Food and Agriculture Organization of the United Nations). 1985. *Water quality for agriculture*. FAO Irrigation and Drainage Paper 29 Rev. 1. Rome.

FAO. 1992. Wastewater treatment and use in agriculture. FAO Irrigation and Drainage Paper 47. Rome.

FAO. 2006. *Livestock's long shadow*. Rome.

FAO. 2011. *World livestock 2011: Livestock in food security*. Rome.

FAO. 2016. *The FAO Action Plan on Antimicrobial Resistance 2016-2020*. Rome. (also available at http://www.fao.org/3/a-i5996e.pdf).

Ferguson, C. & Kay, D. 2012. Transport of microbial pollution in catchment systems. *In* WHO. *Animal waste, water quality and human health*. Geneva.

Gaze, W.H., Zhang, L., Abdouslam, N.A., Hawkey, P.M., Calvo-Bado, L., Royle, J. *et al.* 2011. Impacts of anthropogenic activity on the ecology of class 1 integrons and integron-associated genes in the environment. Ghe *The ISME Journal*, 5: 1253–1261.

Gonzalez, O., Bayarri, B., Acena, J., Perez, S. & Barcelo, D. 2016. Advanced treatment technologies for urban wastewater reuse. *The Handbook of Environmental Chemistry*, 45: 5–38.

La Farré, M., Pérez, S., Kantiani, L. & Barceló, D. 2008. Fate and toxicity of emerging pollutants, their metabolites and transformation products in the aquatic environment. *Trends in Analytical Chemistry*, 27(11).

Liu, L., Oza, S, Hogan, D. *et al.* 2015. Global, regional, and national causes of child mortality in 2000-2013 with projections to inform post-2015 priorities: an updated systematic analysis. *Lancet 2015*, 385: 430-40.

Mallin, M.A., Johnson, V.L., Ensign, S.H. & MacPherson, T.A. 2006. Factors contributing to hypoxia in rivers, lakes, and streams. *Limnology and Oceanography*, 51(1, part 2).

McBride, G., Ross, T. & Dufour, A. 2012. Comparative risk analysis. In WHO (World Health Organization). *Animal waste, water quality and human health*. Geneva.

Monteiro, S.C. & Boxall, A.B.A. 2010. Occurrence and fate of human pharmaceuticals in the environment. *Reviews of Environmental Contamination and Toxicology*, 202: 53-154

Muñoz, I., Gómez-Ramos, M.J., Agüera, A., Fernández-Alba, A.R., García-Reyes, J.F. & Molina-Díaz, A. 2009. Chemical evaluation of contaminants in wastewater effluents and the environmental risk of reusing effluents in agriculture. *Trends in Analytical Chemistry*, 28(6):676–694.

NORMAN (Network of Reference Laboratories, Research Centres and related Organisations for Monitoring of Emerging Environmental Substances). 2016. *List of emerging substances*. (available at www.norman-network.net/?q=node/19).

Reiff, F. 2016. In *Water Quality & Health Council* (online). A cautionary tale of untreated groundwater, campylobacter, and New Zealand's largest drinking water outbreak. http://www.waterandhealth.org/cautionary-tale-untreated-groundwater-campylobacter-zealands-largest-drinking-water-outbreak/.

Thebo, A.L., Drechsel, P., Lambin, E.F. & Nelson, K.L. 2017. A global, spatially-explicit assessment of irrigated croplands influenced by urban wastewater flows. *Environmental Research Letters*, 12: 074008.

Poongothai, S., Ravikrishnan, R. & Murthy, P. 2007. Endocrine disruption and perspective human health implications: a review. *The Internet Journal of Toxicology*, 4 (2).

Schallenberg, M. & Armstrong, A. 2004. Assessment of antibiotic activity in surface water of the lower Taieri Plain and impacts on aquatic bacteria in Lake Waipori, South Otago, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 38(1): 19-28.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2011. A World of SCIENCE. *Natural Sciences Quarterly Newsletter*, 9(4): 1-24. (also available at http://unesdoc.unesco.org/images/0021/002122/212222e.pdf).

UNESCO. 2015a. *International Initiative on Water Quality*. UNESCO International Hydrological Programme. Paris. (also available at http://unesdoc.unesco.org/images/0024/002436/243651e.pdf).

UNESCO. 2015b. *UNESCO Project: Emerging Pollutants in Wastewater Reuse in Developing Countries*. UNESCO-IHP International Initiative on Water Quality (IIWQ). Paris. (also available at http://unesdoc.unesco.org/images/0023/002352/235241E.pdf).

UNESCO. 2017. *Pharmaceuticals in the aquatic environment of the Baltic Sea region - a status report*. UNESCO Emerging Pollutants in Water Series, volume 1. UNESCO-IHP International Initiative on Water Quality. Paris. (also available at http://unesdoc.unesco.org/images/0024/002478/247889e.pdf).

UNESCO. 2018. *Case study on contaminants of emerging concern in Oued Souhil area, Nabeul, Tunisia: occurrence in irrigation water and implications (ECOSI)*. IIWQ Series of Technical and Policy Case Studies. UNESCO Project "Emerging Pollutants in Wastewater Reuse in Developing Countries". Paris.

Vermeulen, L.C., Benders, J., Medema, G., & Hofstra, N. 2017. Global *Cryptosporidium* loads from livestock manure. *Environmental Science & Technology*, 51(15), 8663–8671.

Wellington, E.M.H., Boxall, A.B.A., Cross, P., Feil, E.J., Gaze, W.H., Hawkey, P.M., Johnson-Rollings, A.S. *et al.* 2013. The role of the natural environment in the emergence of antibiotic resistance in Gram-negative bacteria. *The Lancet Infectious Diseases*, 13(2): 155-165.

Wen, Y., Schoups, G. & van de Giesen, N. 2017. Organic pollution of rivers: Combined threats of urbanization, livestock farming and global climate change. *Scientific Reports*, 7: 43289.

WHO (World Health Organization). 2006. *Guidelines for the safe use of wastewater, excreta and grey water. Volume 2: Wastewater use in agriculture*. Geneva. (also available at www.who.int/water_sanitation_health/wastewater/wwuvol2intro.pdf).

WHO. 2011. *Pharmaceuticals in drinking-water*. Geneva

WHO. 2012. *Animal waste, water quality and human health*. Geneva.