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CHAPTER 1. SETTING THE SCENE

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1.1 A global water quality crisis and the role of agriculture

Water pollution is a global challenge that has increased in both developed and developing countries, undermining economic growth as well as the socio-environmental sustainability and health of billions of people.

Although global attention has focused primarily on water quantity, water-use efficiency and allocation issues, the poor management of wastewater and agricultural drainage has created serious water quality problems in many parts of the world, worsening the water crisis (Biswas *et al.*, 2012). Water scarcity is caused not only by the physical scarcity of the resource but also by the progressive deterioration of water quality in many basins, reducing the quantity of water that is safe to use.[1]

As a response, the 2030 Agenda for Sustainable Development acknowledges the importance of water and water quality and includes three water quality targets, one specific to pollution,

[1] The Food and Agriculture Organization of the United Nations (FAO) (www.fao.org/land-water/overview/global-framework/global-framework) and the International Water Management Institute (IWMI) (www.iwmi.cgiar.org) are leading agencies in combating global water scarcity by promoting state-of-the-art sustainable water management scenarios.

in Sustainable Development Goal (SDG) 6[2]. The 2030 Agenda for Sustainable Development is expected to strongly influence future policies and strategies and to ensure that the control of water pollution is elevated in international and national priorities.

While human settlements, industries and agriculture[3] are all key sources of water pollution, in many countries, agriculture is the biggest polluter. Of the 3 928 km^3 of freshwater that is withdrawn every year, it is estimated that only 44% is consumed, mainly through evapotranspiration by irrigated agriculture. The remaining 56% (2 212 km^3 per year) is released into the environment as urban wastewater (approximately 330 km^3), industrial wastewater – including cooling water – (approximately 660 km^3) or agricultural drainage (approximately 1 260 km^3) (AQUASTAT, n.d.b; Mateo-Sagasta *et al.*, 2015).

The composition and level of treatment of these 'wastewaters,' and therefore the risks for human and environmental health, vary. Globally, 80 percent of municipal wastewater is discharged into the environment untreated, and industry is responsible for dumping millions of tonnes of heavy metals, solvents, toxic sludge and other wastes into water bodies every year (Sato *et al.*, 2013; Mateo-Sagasta *et al.*, 2015; WWAP, 2017). Yet irrigation is the largest producer in volume of wastewater (also called agricultural drainage) and livestock produces far more excreta than do humans (FAO, 2006). As a consequence, agriculture remains a key global polluter and is responsible for the discharge of large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage into water bodies (Doetterl *et al.*, 2012; Boxall, 2012; Cañedo-Argüelles *et al.*, 2013; Sutton *et al.*, 2013; Wen *et al.*, 2017). The resultant water pollution poses demonstrated risks to aquatic ecosystems, human health and productive activities (UNEP, 2016).

Industrial agriculture is among the leading causes of water pollution, especially in most high-income countries and many emerging economies, where it has overtaken contamination from settlements and industries as the major factor in the degradation of inland and coastal waters (e.g. eutrophication). Nitrate from agriculture is the most common chemical contaminant in the world's groundwater aquifers (WWAP, 2013). In the European Union, 38 percent of water bodies are under significant pressure from agricultural pollution (WWAP, 2015). In the United States of America, agriculture is the main source of pollution in rivers and streams, the second main source in wetlands and the third main source in lakes (US EPA, 2016). In China, agriculture is responsible

2 SDG Target 6.3: "By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally" (United Nations, 2016).

3 Agriculture refers to crops, livestock and aquaculture.

for a large share of surface water pollution and is almost exclusively responsible for groundwater pollution by nitrogen (FAO, 2013). In many low-income countries and emerging economies, while the large loads of untreated municipal and industrial wastewater are major concerns, the role of cropping systems, livestock and aquaculture in water quality degradation is still unclear but suspected to be increasingly relevant.

Crops and livestock are the main agricultural pollution sources but aquaculture is emerging. Agricultural pressure on water quality come from cropping (including agroforestry) and livestock systems and aquaculture, all of which have expanded and intensified to meet increasing food demand related to population growth and mobility, and changes in dietary patterns. The area equipped for irrigation has more than doubled in recent decades from 139 million hectares – Mha – in 1961 to 320 Mha in 2012 (FAO, 2014). The total number of livestock has more than tripled from 7.3 billion units in 1970 to 24.2 billion units in 2011 (FAO, 2016a). Aquaculture has grown more than twenty-fold since the 1980s, especially inland-fed aquaculture and particularly in Asia (FAO, 2016b).

The global growth of crop production has mainly been achieved through the intensive use of inputs such as pesticides and chemical fertilizers. The trend has been amplified by the expansion of agricultural land, with irrigation playing a strategic role in improving productivity and rural livelihoods, while also transferring agricultural pollution to water bodies.

The livestock sector is growing and intensifying faster than crop production in almost all countries. The associated waste, including manure, has serious implications for water quality (FAO, 2006). In the last 20 years, a new class of agricultural pollutants has emerged in the form of veterinary medicines (antibiotics, vaccines and growth promoters such as hormones), which travel from farms through water to ecosystems and drinking-water sources (Boxall, 2012). Zoonotic water-borne pathogens are another major concern (WHO, 2012).

There has been a dramatic and rapid increase worldwide in aquaculture in marine, brackish-water and freshwater environments (FAO, 2016b). Fish excreta and uneaten feeds from fed aquaculture diminish water quality. Increased production has combined with a greater use of antibiotics, fungicides and anti-fouling agents, which in turn may contribute to polluting downstream ecosystems (Li and Shen, 2013).

The annual costs of water pollution from agriculture exceed billions of dollars.
The costs of agricultural pollution are generally non-market externalities, which are borne by society as a whole. Water pollution from agriculture has direct negative impacts on human health, for example, the well-known blue baby syndrome in which high levels of nitrates in water can cause methaemoglobinemia – a potentially fatal illness

– in infants. Pesticide accumulation in water and the food chain, with demonstrated ill effects on humans, led to the widespread banning of certain broad-spectrum and persistent pesticides (such as DDT and many organophosphates); however, some of these pesticides are still used in poorer countries, causing acute and likely chronic health effects. Aquatic ecosystems are also affected by agricultural pollution. For example, eutrophication caused by the accumulation of nutrients in lakes and coastal waters has impacts on biodiversity and fisheries (Rabalais *et al.*, 2009). Water-quality degradation may also have severe direct impacts on productive activities, including agriculture itself. For example, dam siltation caused by the mobilization of sediment due to erosion is an increasing challenge (Basson, 2008), which has cost many millions of dollars. Irrigation using saline or brackish water has limited agricultural production on hundreds of thousands of hectares worldwide (Mateo-Sagasta, 2010).

A nationwide study in the United States estimated that farm nitrogen pollution costs Americans in the range of US$59–US$340 billion a year (Sobota *et al.*, 2015). In the European Union, van Grinsven *et al.* (2013) estimated the annual cost of pollution by agricultural nitrogen to be in the range of €35–€230 billion per year. Many of these costs are associated with damages to aquatic ecosystems, deteriorating water quality and the associated human health impacts. Despite data gaps, methodological challenges and limited assessments, the Organisation for Economic Co-operation and Development (OECD) estimated that, in its member countries alone, the environmental and social costs of water pollution caused by agriculture probably exceed billions of dollars annually (OECD, 2012). This is particularly apparent when impacts from other agricultural pollutants (see Chapter 3), beyond nitrogen, are accounted for.

Diagnosis, prediction and monitoring are key requirements for the management of aquatic ecosystems and the mitigation of harmful impacts on them. If planners and lawmakers are to design cost-effective measures for preventing pollution and mitigating risks, they need to know the state of aquatic ecosystems, the nature and dynamics of the drivers and pressures that lead to water-quality degradation, and the impacts of such degradation on human health, economics and the environment.

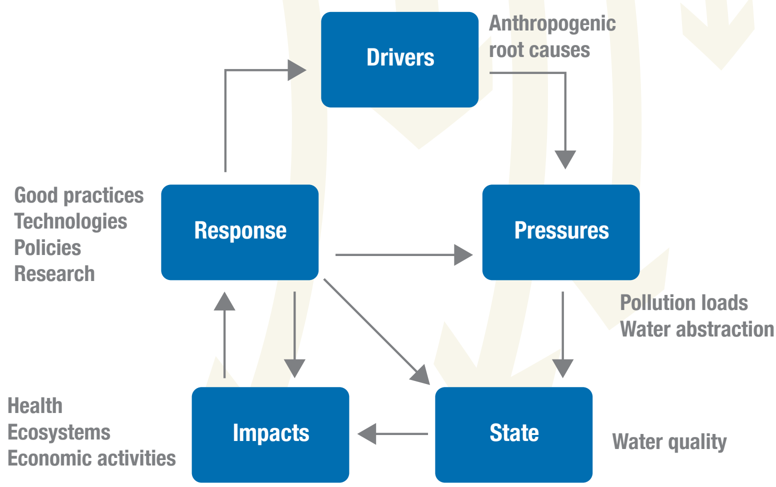
Nevertheless, because of their diffuse nature, it is difficult to identify and quantify agricultural polluters and their relative contribution to the degradation of water quality. The specific processes linking agricultural activities to pollutant concentrations in water are imperfectly understood. Improved baseline and monitoring data on management practices and water quality, together with modelling, are essential to understand the causes and effects of water pollution from agriculture and to identify and plan the right responses.

1.2 What this publication is about

Existing literature provides scattered information on water pollution from agriculture, but does not comprise a comprehensive review, which is what this publication aims to provide. The report seeks to compile and integrate the best available information and data. It covers different rural and agricultural sectors, including crops, livestock and aquaculture, and examines the drivers of water pollution from these sectors, the resulting pressures and changes in water bodies, the associated impacts on human health and the environment, and the responses needed to prevent pollution and mitigate risks.

This publication provides an analysis of problems and options for improvement. It is structured using the Drivers, Pressures, State, Impact, Response (DPSIR) model. DPSIR is a causal framework for describing the interactions between society and the environment (OECD, 1993; European Commission, 2002). The framework has been used to formulate a number of relevant policies for pollution control, including the European Water Framework Directive, and has been used by several UN organizations to produce different global public goods, such as the United Nations University Institute for Environment and Human Security (UNU-EHS)/United Nations Environment Programme (UNEP) international water quality guidelines for ecosystems (UNU-EHS/UNEP, 2016). The DPSIR framework provides a structure within which to present indicators needed to enable feedback to policy-makers on environmental quality and the impact of certain policy choices. Each of the DPSIR components is connected to another (cause-effect) (see Figure. 1.1), but can also be defined individually (Table 1.1).

FIGURE 1.1 DPSIR framework and water quality



Source: Adapted from OECD, 1993; European Commission, 2002.

Table 1.1 | The DPSIR framework, definitions and examples from agriculture

Term	Definition	Examples from agricultural water pollution
Driver	An anthropogenic activity that may have an environmental effect	Primary drivers: population growth and mobility, and change in consumption patterns Secondary drivers: expansion and intensification of irrigated agriculture, rain-fed agriculture, livestock production and inland aquaculture
Pressure	The direct effect of the driver	Loads of nitrogen, phosphorus, pesticides, biochemical oxygen demand, sediments, salts, organic matter, pathogens or emerging pollutants generated on-farm (at source) and reaching water bodies (e.g. rivers, lakes, aquifers, coastal waters, marine waters)
State	The condition of the water body resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics of the water body)	Concentration of ammonia, nitrate phosphate, persistent organic pollutants, suspended solids and other agricultural pollutants in water bodies (e.g. rivers, lakes, aquifers, coastal waters, marine waters)
Impact	The effects of the pressure on the environment, health and the economy	ENVIRONMENT: e.g. fish killed, ecosystems modified-eutrophication HEALTH: e.g. increased human mortality or morbidity resulting from water pollution by agriculture ECONOMY: e.g. as a result of unsafe agricultural products irrigated with polluted waters or a decrease in productivity due to toxicity or salinity/sodicity
Response	The measures taken to improve the state of the water body or to mitigate the impacts of water quality degradation	Responses on drivers (including change in diets and consumption habits), pressures (including pollution prevention on-farm), state (including remediation or restoration of ecosystems) and impacts (including the control of human exposure to polluted waters)

Note: The distinction made here between state and impact separates effects that are sometimes combined, or confused. One reason for this is that because many of the impacts are not easily measurable, state is often used as an indicator of, or surrogate for, impact.

Source: adapted from the European Commission, 2002.

Although there are other important externalities resulting from agriculture expansion and intensification (e.g. greenhouse gas emissions or loss of habitat and biodiversity), the principal focus of the following chapters is water pollution induced by agriculture. Issues such as water resources depletion or soil erosion by agriculture will be only discussed as contributors to water quality degradation.

The report aims to provide:

- A GLOBAL DIAGNOSIS: When data is available, the report shows where major water quality problems are, what role agriculture plays in these problems and what are the driving forces behind them.
- RESPONSES: The report lists and describes major mitigation and remediation options at the policy level (e.g. strategies, regulations, economic instruments, cooperative agreements, education and awareness), at the farm level (e.g. best practices for agricultural inputs or for erosion control) and off-farm (e.g. vegetated buffers zones or constructed wetlands).
- A SYSTEMATIC METHODOLOGY: The report provides policymakers and practitioners with the definitions and examples they can follow to make a DPSIR analysis for agricultural water pollution. This methodology is applicable at country, river basin or watershed levels

The DPSIR analytical and response framework can include the concept of 'adaptive management,' which involves periodically assessing the results and benefits of remedial activities, and enhancing or modifying them to achieve more effective outcomes (Pahl-Wostl, 2006). Adaptive management underpins sustainable natural resource management strategies in countries such as Australia and New Zealand. Adaptive management recognizes that there may be unforeseen outcomes, synergies and impacts of responses to problems, and that achieving coherence in policy, strategy, planning and practical activities is an iterative and often cyclical process.

Much of the science, routine monitoring and regulatory and institutional development for the better management of water quality have already occurred in the developed world. There is thus a bias in both literature and experience towards the OECD nations, whereas the major emerging challenges lie in the rest of the world, where the extent and severity of the problems are not yet evident or well understood. This publication will reflect this asymmetry in information and experience.

Crucially, public and private resources are stretched in many other directions. Despite differences in context, there is much that transitional and developing countries can learn from the expensive consequences of environmental degradation in industrialized countries, giving them the potential to avoid such consequences themselves. In general, however, this publication contends that cost-effective and targeted management of agricultural non-point source pollution requires a good understanding of the context and detailed processes involved.

1.3 How to use this publication

The report is divided into three different sections, which sequentially introduce the report and review the key drivers of agricultural water pollution (Part 1: chapters 1-2); analyze the related pollution loads, state change in water bodies and resulting impacts on human health and ecosystems (Part 2: chapters 3-9); and explore different approaches to controlling water pollution from agriculture, including policies and institutional arrangements, and on-farm and off-farm responses (Part 3: Chapters 11-12). Examples will be drawn from developed and developing countries.

Chapter 2 examines the driving forces that result in the use and abuse of agricultural inputs, which in turn cause undesirable effects on the receiving waters. The chapter reviews trends in population growth and changes in diet and food demand, and examines how such changes have driven agricultural expansion and intensification, with the increased use of agriculture inputs (fertilizers, pesticides, animal feed, medicines, etc.) per unit of land.

Determining the agricultural pressures on receiving waters is complex, and the multiple factors that govern the emergence of state changes and impacts require an understanding of process and the quantity of pollutant loads. Chapters 3-8 seek to describe the processes linking pollution loads to state change of receiving waters (e.g. rivers, lakes, reservoirs, groundwater or coastal zones) and to the resulting impacts on human health and ecosystems. When available, data and information on pressures, state and impacts are presented by pollutant type, including nutrients, pesticides, salts, sediments, organic matter, pathogens and emerging pollutants. Achieving a full understanding of the relationship between pressures, state change and impacts typically requires modelling and Chapter 9 reviews existing models and their potential role, scope and application.

Pollution management requires that the sources of pollutant loads are identified so that appropriate mitigating measures can be applied. There is a broad range of approaches to managing pollutant export from farms, through broad legislative and financial measures that restrict input use, encourage greater efficiency, or actively limit the export of pollutants. Landscapes can also be managed to reduce the movement or accumulation of some pollutants and thus reduce pressure on receiving waters. In the absence of a precise understanding of cause and effect, broadly targeted regulations and controls may be applied. Practical approaches to mitigating the generation and transmission of agricultural pollutants are presented at river basin and catchment scales, down to farm and field level. All of this is covered in Chapters 10 and 11. The main messages and conclusion of the report are summarized in Chapter 12.

If you belong to the international development community, this publication will help you to identify agricultural pollution hotspots worldwide and will provide guidance on how to decouple agriculture development from water pollution though sustainable intensification.

If you are a national water policy-maker, we hope this publication will a) encourage you to adopt and apply the DPSIR approach to water quality and b) offer you a selection of water pollution prevention and remediation actions that can be undertaken at local and landscape levels. National public policy at large and health and economic sectors that rely on water of adequate quality may benefit from this publication as well.

If you are an agricultural practitioner, this report will help you understand how crop production, livestock breeding or aquaculture can impact water bodies, with serious consequences for society. It can also guide you on how to minimize your sector's footprint on water quality.

If you are a researcher, this publication will help you to identify the main knowledge gaps and research needs related to agricultural water pollution analysis and control.

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