Food and Agriculture Organization of the United Nations

RESEARCH PROGRAM ON Water, Land and Ecosystems

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Water pollution from agriculture: a global review

Executive summary

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Published by
the Food and Agriculture Organization of the United Nations
Rome, 2017
and the International Water Management Institute on behalf of
the Water Land and Ecosystems research program
Colombo, 2017

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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 physical and environmental health of billions of people.

Although global attention has focused primarily on water quantity, water-use efficiency and allocation issues, poor wastewater management has created serious water-quality problems in many parts of the world, worsening the water crisis. Global water scarcity is caused not only by the physical scarcity of the resource but also by the progressive deterioration of water quality in many countries, reducing the quantity of water that is safe to use.[1]

The 2030 Agenda for Sustainable Development acknowledges the importance of water quality and includes a specific water quality target in Sustainable Development Goal (SDG) 6.[2] The 2030 Agenda for Sustainable Development is expected to strongly

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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.

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).

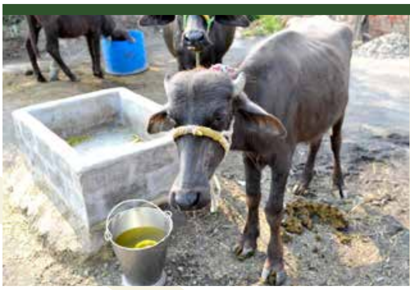
influence future policies and strategies and to ensure that the control of water pollution is elevated in international and national priorities.

Human settlements, industries and agriculture[3] are the major sources of water pollution. Globally, 80 percent of municipal wastewater is discharged into water bodies untreated, and industry is responsible for dumping millions of tonnes of heavy metals, solvents, toxic sludge and other wastes into water bodies each year (WWAP, 2017). Agriculture, which accounts for 70 percent of water abstractions worldwide, plays a major role in water pollution. Farms discharge large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage into water bodies. The resultant water pollution poses demonstrated risks to aquatic ecosystems, human health and productive activities (UNEP, 2016).

In most high-income countries and many emerging economies, agricultural pollution has already 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 significantly under 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 for a large share of surface-water pollution and is responsible almost exclusively for groundwater pollution by nitrogen (FAO, 2013). In low-income countries and emerging economies, the large loads of untreated municipal and industrial wastewater are major concerns. Nevertheless, agricultural pollution, aggravated by increased sediment runoff and groundwater salinization, is also becoming an issue.

Agricultural pressures on water quality come from cropping and livestock systems and aquaculture, which have all expanded and intensified to meet increasing food demand related to population growth 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) and 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 20-fold since the 1980s, especially inland fed aquaculture and particularly in Asia (FAO, 2016b).

[3] Agriculture refers to cropping activities, livestock and aquaculture.


Neil Palmer (IWMI)

> **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**

The global growth of crop production has been achieved mainly 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 [hormones]), which move from farms through water to ecosystems and drinking-water sources. Zoonotic waterborne pathogens are another major concern (WHO, 2012).

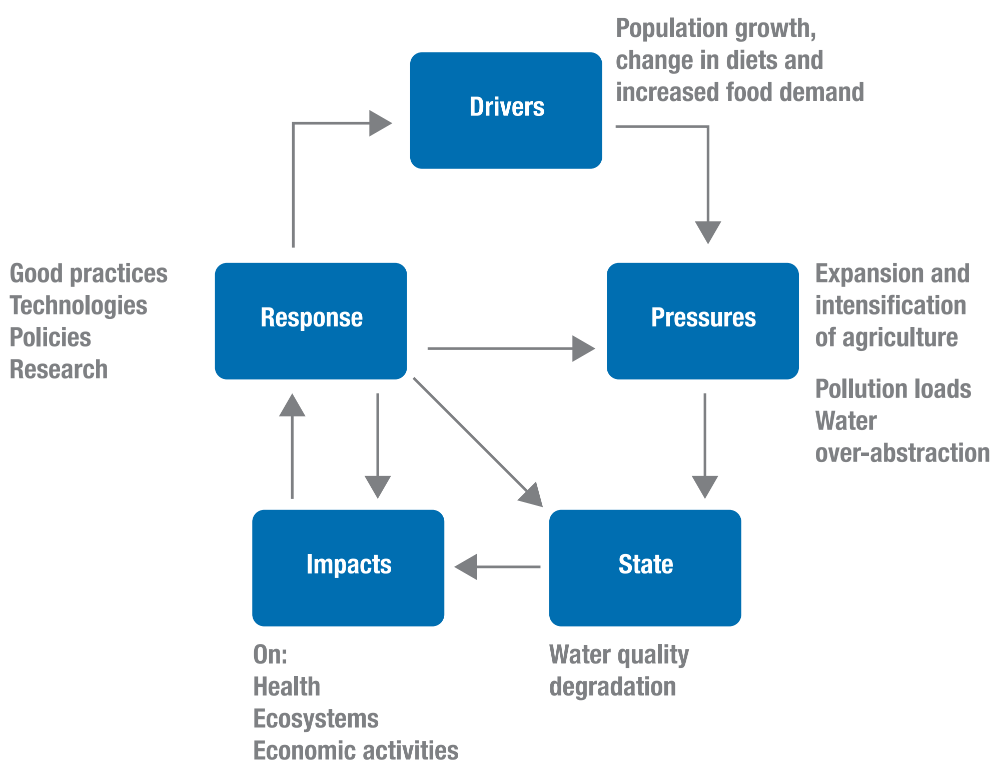
There has been a dramatic and rapid increase in aquaculture worldwide in marine, brackish-water and freshwater environments (FAO, 2016b). Fish excreta and uneaten feeds from fed aquaculture diminish water quality. Increased production has combined with greater use of antibiotics, fungicides and anti-fouling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

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), but some such 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. Water-quality degradation may also have severe direct impacts on productive

activities, including agriculture. For example, dam siltation caused by the mobilization of sediment due to erosion has cost many millions of dollars. Irrigation using saline or brackish water has limited agricultural production in hundreds of thousands of hectares worldwide. In Organisation for Economic Co-operation and Development (OECD) countries alone, the environmental and social costs of water pollution caused by agriculture probably exceed billions of dollars annually (OECD, 2012a).

Diagnosis, prediction and monitoring are key requirements for the management of aquatic ecosystems and the mitigation of harmful impacts on them. If they are to design cost-effective measures for preventing pollution and mitigating risks, managers, planners and lawmakers 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 and the environment. The sections below follow the logic of the Drivers-Pressures-State change-Impact-Response (DPSIR) framework (Figure 1) to present a summary of causes and effects of water pollution in agriculture as well as possible responses to prevent pollution and mitigate its impacts.

FIGURE 1 DPSIR framework for analysing water pollution in agriculture

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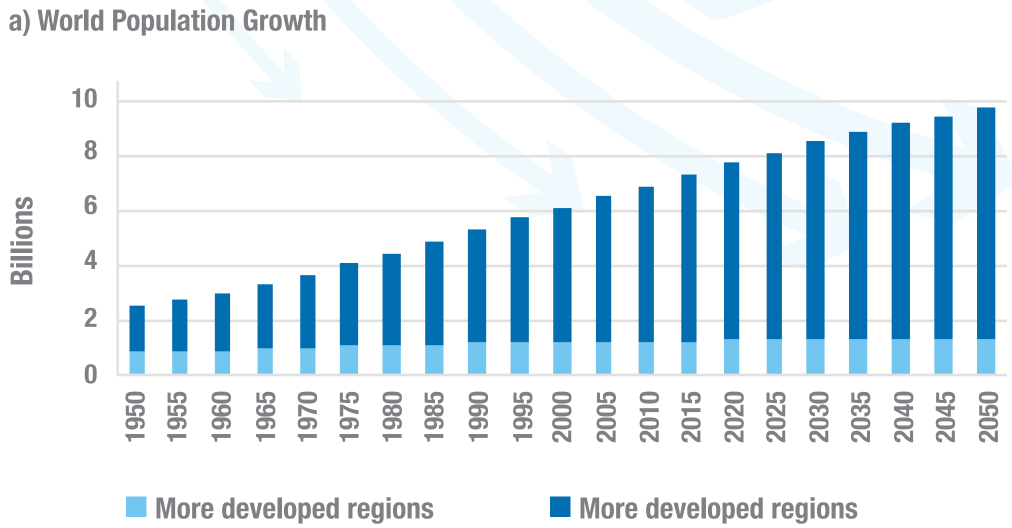
POPULATION GROWTH, CHANGES IN DIETS, AND INCREASING FOOD DEMAND

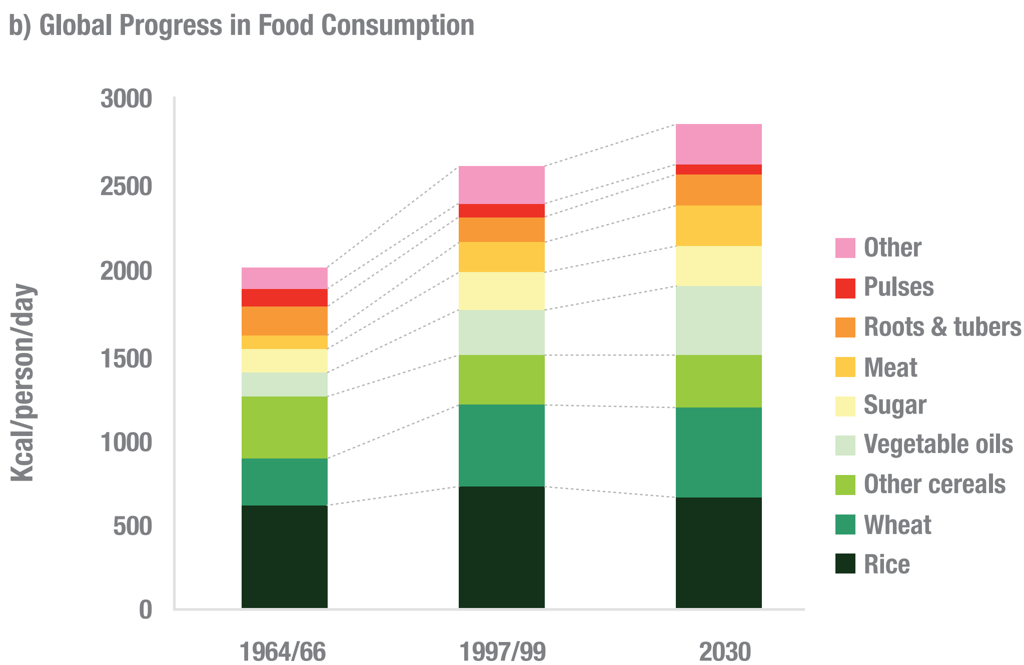
The global population is projected to reach 9.8 billion people by 2050 (UNDESA, 2017) Population growth and changes in consumption patterns, including new dietary preferences (Figure 2) require the production of more (and more diverse) food. This, in turn, is driving agricultural expansion and intensification and bringing new environmental externalities, including impacts on water quality.

Average calorie intake has increased as populations have become richer (despite the continuing large number of people living in absolute poverty). Diets are changing from those based mostly on grains and carbohydrates towards those with larger proportions of meat, eggs, dairy, oils and other resource-intensive products (Figure 2) (FAO, 2009). Excessive consumption (which is leading to overnutrition and obesity, even in middle- and low-income countries) and post-harvest losses and waste draw down scarce resources and increase environmental footprints, including the degradation of water quality (FAO, WFP and IFAD, 2012).

The need to produce more food implies an increase in land clearing for food production and in the productivity of agricultural lands. The required rise in agricultural production cannot continue to occur, however, at the expense of the environment, which has been the case in the last decades. Business as usual may be insufficient to meet growing needs and cannot be sustained.

FIGURE 2 a) Past and expected global population, by developed and developing countries
b) Global food consumption patterns, 1964–2030





Sources: a) UNDESA 2017; b) FAO, 2009.

EXPANSION AND INTENSIFICATION OF AGRICULTURAL SYSTEMS

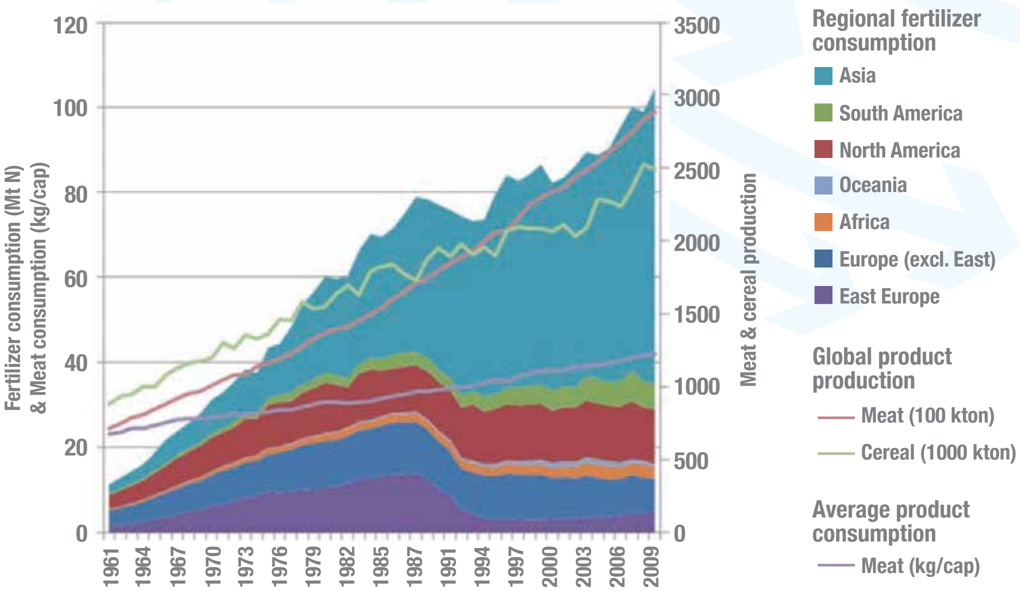
Agricultural systems have expanded and intensified in response to the ever-increasing demand for food. In absolute terms, land clearing and agricultural expansion have contributed to higher pollutant loads in water, but probably the biggest impacts have been caused by certain unsustainable patterns of agricultural intensification. The overuse and misuse of agrochemicals, water, animal feeds and drugs designed to increase productivity have resulted in higher pollution loads in the environment, including rivers, lakes, aquifers and coastal waters.

The following sections review the unsustainable trajectory followed by agri-food systems and identify hotspots where crop production, livestock and aquaculture may be the key contributors to the degradation of water quality.

Cropping systems

The world population doubled between about 1970 and 2015, but the production of cereals almost tripled, the production of vegetables increased fourfold, tomato production increased fivefold and soybean production increased eightfold (FAO, 2016a). This huge increase in production was achieved through the expansion of agricultural land, the introduction of new crop varieties, and the more intensive use of agrochemicals and agrotechnologies.

FIGURE 3 Total mineral fertilizer consumption in major world regions, global cereal and meat production, and per capita meat consumption, 1961–2009



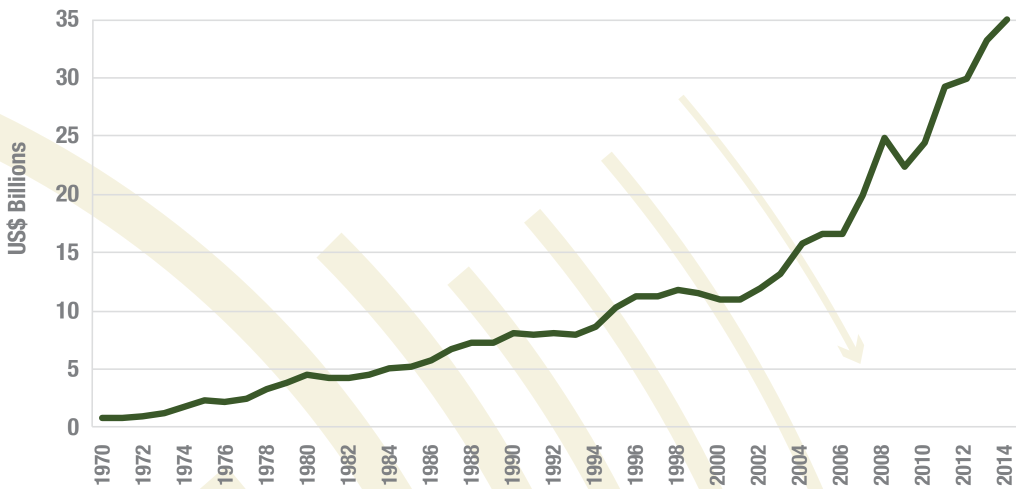
Source: Sutton *et al*., 2013.

Irrigation is a major factor in agricultural intensification. Big irrigation projects have been important means for increasing food security globally and particularly in developing countries. Nevertheless, irrigation and drainage have often been associated with a loss of water quality caused by salt, pesticides and fertilizer runoff and leaching.

Mineral fertilizers have been used since the nineteenth century to supplement natural nutrient sources and recycling to raise crops and animals, but the use of such fertilizers has increased dramatically in recent decades (Figure 3). Today, the world consumes ten times more mineral fertilizer than it did in the 1960s (FAO, 2016a). Rockström *et al*. (2009) suggested that the mobilization of nutrients could already have exceeded thresholds that will trigger abrupt environmental change in continental-to-planetary-scale systems. Fertilizer use has not grown evenly worldwide. Major disparities exist between those parts of the world with too many nutrients and those with insufficient. Key regions where excess nutrients are being transferred to water bodies include North America, Europe, and parts of South and East Asia.

In the trajectory of land-use intensification, countries have increasingly adopted a pest management approach based on the use of synthetic pesticides. Today, pesticide production is a multibillion dollar industry, with the global market worth more than USD 35 billion per year (nominal) (Figure 4; FAO, 2016). Several upper-middle-

FIGURE 4 Value of global pesticide trade, 1970–2014



Source: FAO, 2016

income countries (e.g. Argentina, Brazil, Malaysia, South Africa and Uruguay) and lower-middle-income countries (e.g. Cameroon, Cape Verde, Nicaragua, Pakistan and Ukraine) have experienced double-digit growth in the intensity of pesticide use, albeit sometimes from a low base. Costa Rica, Colombia, Japan and Mexico have the highest pesticide use intensities worldwide (Schreinemachers and Tipraqsa, 2012). In general, the proportion of herbicides in pesticide global consumption increased rapidly, while the proportion of fungicides and insecticides declined (Zhang, Jiang and Ou, 2011).

In developing countries, the fast rate of growth in pesticide use, reliance on broad-spectrum pesticides, weak institutional frameworks, weak rule enforcement, and limited knowledge and awareness among farmers on the use of hazardous chemicals pose enormous challenges to the safe and sustainable management of pesticides.

Livestock production

Livestock production accounts for 70 percent of all agricultural land and 30 percent of the land surface of the planet. The livestock sector is one of the top three contributors to the most serious environmental problems, including water-quality degradation, at every scale from local to global (FAO, 2006).

Demand for and the production of livestock products are increasing rapidly globally, but the following regions take centre stage: central and eastern United States of America; southern Brazil, Uruguay and northern Argentina; Europe; India; and China.

The major structural changes occurring in the livestock sector are associated with the development of industrial and intensive livestock production systems, which often involve large numbers of animals concentrated in relatively small areas. Intensive livestock systems increasingly depend on feed concentrates that are traded domestically and internationally. These changes are exerting growing pressure on the environment and particularly on water quality. Most of the water used for livestock drinking and servicing returns to the environment in the form of liquid manure, slurry and wastewater. Livestock excreta contain considerable quantities of nutrients, oxygen-depleting substances and pathogens and, in intensive systems, also heavy metals, drug residues, hormones and antibiotics. When livestock is concentrated, the associated production of wastes tends to go beyond the buffering capacity of surrounding ecosystems, thereby polluting surface waters and groundwater.

Aquaculture production

Demand for fish and shellfish for food, feed and other products has grown faster than for any other agricultural commodity in the last several decades. Wild fish catches plateaued in the 1990s and all increases in fish production, therefore, have derived from aquaculture, which has expanded dramatically and now produces nearly half the total quantity of fish consumed. Total global aquatic animal production reached 167 million tonnes in 2014 (FAO, 2016b), of which an estimated 146 million tonnes was consumed directly by humans.

Overwhelmingly, the growth of aquaculture has taken place in developing countries, which produce 91 percent of global output; the greatest concentration of aquaculture is in low-income developing nations. Asia is by far the larger producer of aquacultural output, with almost 90 percent of world production, with output from China dominating at 45.5 million tonnes per year (FAO, 2016b).

There has also been a steady increase in the proportion of fed species in aquaculture that require externally produced foods; this form of production accounts for 70 percent of total production, compared with 50 percent in 1980. Fed and intensive aquaculture can result in export of faeces, uneaten feed and drugs to water bodies. Carnivorous species are of high value in aquaculture, and these require large inputs of fishmeal and other pelleted feeds. Many types of non-fed aquaculture (e.g. mussel farming) can filter and clean waters, but other types (e.g. intensive caged crab culture) may disrupt natural nutrient cycles and result in the degradation of water quality.

Market pressures and differentiation are increasing the intensity of production and leading to increased concentrations of single species. These trends have resulted in an increase in the use of medicines (e.g. antibiotics, fungicides and anti-fouling agents), which in turn contribute to downstream pollution.

AGRICULTURAL POLLUTANTS: SOURCES AND EFFECTS

Major agricultural contributors to water pollution (and the main targets for water-pollution control) are nutrients, pesticides, salts, sediments, organic carbon, pathogens, metals and drug residues. Table 1 shows the relative contributions of these to water-quality degradation. The importance of different forms of agricultural pollution varies with individual situations, and negative impacts such as eutrophication (which may include sediments, nutrients and organic matter) arise from combinations of stressors.

Nutrients

In crop production, water pollution from nutrients occurs when fertilizers are applied at a greater rate than they are fixed by soil particles or exported from the soil profile (e.g. by plant uptake or when they are washed off the soil surface before plants can take them up). Excess nitrogen and phosphates can leach into groundwater or move via surface runoff into waterways. Phosphate is not as soluble as nitrate and ammonia and tends to get adsorbed onto soil particles and enter water bodies thorough soil erosion.

In livestock production, feedlots are often located on the banks of watercourses so that (nutrient-rich) animal waste (e.g. urine) can be released directly into those watercourses. Manure is usually collected for use as organic fertilizer, which, if applied in excess, will lead to diffuse water pollution. In many cases, too, manure is not stored in contained

TABLE 1 | Categories of major water pollutants in agriculture and the relative contributions of the three main agricultural production systems

Pollutant category	Indicators/examples	Relative contribution by:		
		Crops	Livestock	Aquaculture
Nutrients	Primarily nitrogen and phosphorus present in chemical and organic fertilizers as well as animal excreta and normally found in water as nitrate, ammonia or phosphate	***	***	*
Pesticides	Herbicides, insecticides, fungicides and bactericides, including organophosphates, carbamates, pyrethroids, organochlorine pesticides and others (many, such as DDT, are banned in most countries but are still being used illegally and persistently)	***	-	-
Salts	E.g. ions of sodium, chloride, potassium, magnesium, sulphate, calcium and bicarbonate. Measured in water, either directly as total dissolved solids or indirectly as electric conductivity	***	*	*
Sediment	Measured in water as total suspended solids or nephelometric turbidity units – especially from pond drainage during harvesting	***	***	*
Organic matter	Chemical or biochemical oxygen-demanding substances (e.g. organic materials such as plant matter and livestock excreta), which use up dissolved oxygen in water when they degrade	*	***	**
Pathogens	Bacteria and pathogen indicators. E.g. Escherichia coli, total coliforms, faecal coliforms and enterococci	*	***	*
Metals	E.g. selenium, lead, copper, mercury, arsenic and manganese	*	*	*
Emerging pollutants	E.g. drug residues, hormones and feed additives	-	***	**

areas and, during significant rainfall events, it can be washed into watercourses via surface runoff.

In fed aquaculture, nutrient loads delivered to water bodies are primarily a function of feed composition and feed conversion (faecal wastes). Uneaten feed in intensive fed aquaculture can be a significant contributor to nutrient loads in water.

Together with other stressors, high nutrient loads can cause the eutrophication of lakes, reservoirs, ponds and coastal waters, leading to algae blooms that suppress other aquatic plants and animals. Despite data gaps, 415 coastal areas have been identified worldwide as experiencing some form of eutrophication, of which 169 are hypoxic (WRI, 2008). The excessive accumulation of nutrients may also increase adverse health impacts, such as blue-baby syndrome, due to high levels of nitrate in drinking-water.

Pesticides

"Millions of tonnes of active pesticide ingredients are used in agriculture each year"

Insecticides, herbicides and fungicides are applied intensively in agriculture in many countries (Schreinemachers and Tipraqsa, 2012). When improperly selected and managed, they can pollute water resources with carcinogens and other toxic substances that can affect humans. Pesticides may also affect biodiversity by killing weeds and insects, with negative impacts up the food chain. In developed countries, although considerable use of older broad-spectrum pesticides persists, the trend is towards the use of newer pesticides that are more selective and less toxic to humans and the environment and which require lower quantities per unit area to be effective.

Nevertheless, millions of tonnes of active pesticide ingredients are used in agriculture (FAO, 2016a). Acute pesticide poisoning causes significant human morbidity and mortality worldwide – especially in developing countries, where poor farmers often use highly hazardous pesticide formulations.

Salts

The production of brackish drainage and leaching water in agriculture has grown proportionally with the increase in irrigation in recent decades.

Irrigation can mobilize salts accumulated in soils (leaching fractions), which are then transported by drainage water to receiving water bodies and cause salinization. Excessive irrigation can also raise water tables from saline aquifers and increase the seepage of saline groundwater into watercourses. The intrusion of saline seawater into aquifers – frequently the result of excessive groundwater extractions for agriculture – is another important cause of salinization in coastal areas (Mateo-Sagasta and Burke, 2010).

A. Gandolfi

"Whenever salinity increases, the biodiversity of microorganisms, algae, plants and animals declines"

Major water-salinity problems have been reported in Argentina, Australia, China, India, the Sudan, the United States of America, and many countries in Central Asia (FAO, 2011). In 2009, approximately 1.1 billion people lived in regions that had saline groundwater at shallow or intermediate depths (IGRAC, 2009).

Highly saline waters alter the geochemical cycles of major elements – such as carbon, iron, nitrogen, phosphorus, silicon and sulphur (Herbert *et al*., 2015) – with overall impacts on ecosystems. Salinization can affect freshwater biota by causing changes within species and in community composition and can ultimately lead to biodiversity loss and migration. In general, when salinity increases, the biodiversity of microorganisms, algae, plants and animals declines (Lorenz, 2014).

Sediments

Unsustainable land use and improper tillage and soil management in agriculture are increasing erosion and sediment runoff into rivers, lakes and reservoirs, with massive quantities of soil lost and transported to water bodies every year. The global rate of erosion in croplands is estimated at 10.5 megagrams (Mg) per ha per year, which corresponds to 193 kilograms of soil organic carbon per ha per year. Estimates for pastureland are lower, at 1.7 Mg per ha per year, which is equivalent to 40.4 kilograms of soil organic carbon per ha per year. It is estimated that 43 percent of the agricultural sediment flux is in Asia (Doetterl, Van Oost and Six, 2012).

High rates of erosion occur in areas where precipitation is high, slopes are steep and vegetation cover is poor. Erosion is aggravated by overgrazing in pasturelands, by inappropriate ploughing on steep slopes and, more broadly, by deforestation, landclearing and the degradation of riverine vegetation.

Sediment in river systems is a complex mixture of minerals and organic matter, potentially including physical and chemical pollutants. Sediments can cover and destroy fish spawning beds, clog fish gills, and reduce useful storage volume in reservoirs. Sedimentation can damage watercourses, choke streams and make filtration necessary for municipal and irrigation water supplies. It can also affect delta formation and dynamics and limit the navigability of water bodies.

Particles of clay and silt in sediment can adsorb many types of chemicals on their surfaces, including nutrients, heavy metals and persistent organic pollutants. Sediment, therefore, is a key means by which such pollutants are transported to water bodies.

Organic matter

Organic matter from animal excreta, uneaten animal feed, animal-processing industries and mismanaged crop residues are all significant water pollutants. Livestock-related wastes have among the highest biological oxygen demand (BOD). For example, the BOD of pig slurry is in the range of 30 000–80 000 milligrams per litre, compared with the typical BOD of domestic sewage of 200–500 milligrams per litre (FAO, 2006). Locally, aquaculture can be 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. The discharge of organic matter also increases the risk of eutrophication and algal blooms in lakes, reservoirs and coastal areas.

"The global rate of erosion in croplands is estimated at 10.5 megagrams (Mg) per ha per year, which corresponds to 193 kilograms of soil organic carbon per ha per year"

Pathogens

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

"Some pathogens can survive for days or weeks in the faeces discharged onto land and may later contaminate water resources via runoff"

Pathogens from livestock that are detrimental to public health include bacteria such as Campylobacter spp., Escherichia coli O157:H7, Salmonella spp. and 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).

Emerging pollutants

New agricultural pollutants such as antibiotics, vaccines, growth promoters and hormones have emerged in the last two decades. These can reach water via leaching and runoff from livestock and aquaculture farms, as well as through the application of manure and slurries to agricultural land (OECD, 2012b). Residues of heavy metals in agricultural inputs such as pesticides and animal feed are also emerging threats. Today, more than 700 emerging pollutants and their metabolites and transformation products are listed as present in European aquatic environments (NORMAN, 2016).

Agriculture is not only a source of emerging pollutants, it also contributes to the spread and reintroduction of such pollutants into aquatic environments through wastewater (re)use for irrigation and the application of municipal biosolids to land as fertilizers. An estimated 35.9 Mha of agricultural lands are subject to the indirect use of wastewater (Thebo *et al.*, 2017). The potential risks to human health posed by exposure to emerging pollutants via contaminated agricultural products needs attention.

LINKING POLLUTION CAUSES AND EFFECTS: ROLE OF MODELS

Models provide representations of systems in the real world, a holistic understanding of problems by identifying relationships (cause and effect), and future predictions (scenarios). Models can simulate the fate of pollutants and the resulting change in state of water quality and help in understanding the impacts on human health and ecosystems. Models can also help in determining the effectiveness and costs of remedial actions.

As a first step towards effective water-quality management, it is necessary to know the current status of water quality and the spatial and temporal distribution patterns of any contaminant emissions, loads and concentrations in water environments. For example, if pollutant loads exported to a given water body are high, identifying where, when and by whom the pollutant sources are emitted is necessary to ensure appropriate responses.

Well-calibrated models capture the key processes between pressures, states and impacts at appropriate spatial scales. Moreover, existing models are increasingly robust to allow the prediction of future conditions and analyses of "what if?" questions concerning outcomes under existing, past and forecast future conditions.

Because the costs of mitigation are often considerable and expended well in advance of the materialization of benefits, modelling can be a cost-effective way of providing

chance that policies, strategies and actions are on the right track.

Monitoring and modelling are essential and complementary activities. Monitoring is required to determine the state of farms and waterways and to quantify the loads reaching water bodies and the sea (pressures). Existing impacts can often be measured directly, but modelling is required to predict their nature and severity in the future. Data are required to calibrate simulations of key processes and outcomes. Models, as well as economic tools developed in environmental economics, can help in estimating the costs of mitigation.

Dozens of models with different strengths and limitations are used in the field of water quality. These can be applied at different scales (Borah and Bera, 2004; Wang *et al.*, 2013) to support planners and policy-makers in designing cost-effective measures for addressing water pollution in agriculture.


Nana Kofi Acquah for IMWI

RESPONSES

Water pollution in agriculture is complex and multidimensional, and its effective management requires a comprehensive package of responses. Such responses need to act on key drivers of agricultural expansion and intensification, such as unsustainable dietary shifts and food waste and loss; limit the export of pollutants from farms; protect water bodies from agricultural pollution loads; and help restore already-affected water bodies. Responses for influencing both farm- and landscape-scale practices may include regulation; the use of economic instruments; education and awareness-raising; cooperative agreements; and research and innovation.

Acting on drivers

Sustainable diets and reduced food waste

Different diets have different environmental footprints. The increase in demand for food with high environmental footprints, such as meat from industrial farms, is contributing to unsustainable agricultural intensification and to water-quality degradation. This can be changed, however. The right policies and incentives can encourage diets that are more sustainable and healthy and thereby moderate increases in food demand. For example, financial incentives such as taxes and subsidies on food and coupons for consumers have been shown to positively influence dietary behaviour (Purnell *et al.*, 2014). Nevertheless, there is little evidence that environmental food labelling is playing a major role in the food choices of consumers; this approach would need to be combined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> **The increase in demand for food with high environmental footprints, such as meat from industrial farms, is contributing to unsustainable agricultural intensification and to water-quality degradation**

with broader environmental awareness campaigns to turn a general concern among consumers about sustainability into behavioural change (Grunert, Hieke and Wills, 2014).

Another key issue relates to food supply and how food systems will respond to the projected growth in food demand. Food losses and waste should be reduced as much as possible to bring food-production needs closer to actual food demand and to minimize the waste of resources and associated environmental impacts. About one-quarter of produced food is lost along the food-supply chain. The production of this lost and wasted food accounts for 24 percent of the freshwater resources used in food-crop production, 23 percent of total global cropland area and 23 percent of total global fertilizer use (Kummu *et al.*, 2012). Nitrogen pollution is particularly important for water quality: Grizzetti *et al*. (2013) calculated the nitrogen delivered to the environment associated with global food waste at 6.3 teragrams per year, and they estimated that, in the European Union, 12 percent of water nitrogen diffuse pollution in agriculture is linked to food waste. FAO has extensively reviewed options for reducing food loss and waste (e.g. FAO, 2013; FAO, 2015).

Policy instruments

Well-known principles for reducing pollution, such as "polluter pays", are hard to apply in practice to non-point agricultural pollution because identifying the actual polluters is neither easy nor cheap.

Typical regulatory instruments include prohibitions on the direct discharge of pollutants; limits on the marketing and sale of dangerous products; and restrictions on agricultural practices or the location of farms. Regulatory approaches require inspection or self-reporting to ensure compliance, with violations subject to penalties such as fines and compensation payments; enforcement remains a challenge, however.

A broader range of measures has evolved as experience has been gained. Recent analyses suggest that a combination of approaches (regulations, economic incentives and information) works better than regulations alone (OECD, 2008). Policies addressing water pollution in agriculture should be part of an overarching water policy framework at the national or river-basin scale, with all pollutants and polluters considered together. Economic instruments are increasingly employed to improve or replace simple legal provisions or regulations. They include taxes (e.g. on pesticides according to the level of hazard), "set-asides" (the conversion of agricultural land to natural uses), and payments to limit production or the intensity of land use: for example, Norway and Switzerland make substantial payments to farmers for "landscape maintenance", and the Conservation Reserve Program in the United States of America pays farmers to take land out of production for specified periods.

Policies to change farmer behaviour and incentivize the adoption of good practices are key to preventing pollution at the source. Such policies need to include (free) advisory services and training for farmers. Demonstrating the economic benefits to farmers of adopting good practices has also been shown to be effective. Benchmarking can promote behavioural change among farmers by showing them how they perform compared with their peers (without identifying the best and worst individuals). Benchmarking can be applied to the application of fertilizers, manure and slurries, and pesticides. A more subtle form of persuasion is the incorporation of environment modules into school curricula and involving students in raising environmental issues in their communities.

"Water-quality targets need to be realistic and time-bound. They need to balance the costs of adopting a solution and the benefits brought about by higher water quality"

Sanjini de Silva/IWMI

There is increasing interest in cooperative and voluntary agreements – typically between farmers, water suppliers and authorities – as a means for implementing better environmental practices in agriculture. In some cases, private water suppliers have signed agreements with farmers to limit practices (e.g. nitrogen use) that may compromise water quality (and therefore their products), with the costs paid by the water supplier and ultimately borne by water consumers. In other cases, specific areas in river catchments have been identified as major contributors of sediment (and

sediment-borne pollutants) to important ecosystems. To address this, cooperative agreements can be developed between landowners and relevant authorities to reduce erosion, potentially incentivized by policies in favour of agro-environmental payments.

Regulations to protect water quality need to be enforceable. Water-quality targets also need to be realistic and time-bound, and they need to balance the costs of adopting a solution and the benefits brought about by higher water quality. Also, water-quality targets need to take into account time lags between the introduction of a given practice and measurable outcomes (this is particularly relevant in the restoration of aquifer water quality). Once a target is set, planners need to find the most cost-effective combination of policy instruments; typically, pollution prevention will be cheaper than the restoration of affected aquatic ecosystems.

When formulating and implementing policies, priority should be given to major polluters and to water bodies where pollution is highest. The smart identification of pollution hotspots, for example in areas of major livestock concentrations, can help in prioritizing interventions.

Finally, policies need to be coherent. Interventions aimed at increasing food production and farm income on the one hand and at mitigating pollution on the other should be mutually supportive – or at least not conflicting, although this may be hard (politically) to achieve in practice. For example, the subsidies frequently in place for agrochemicals do not act as an incentive for efficient use, and they encourage farming on more fragile lands. Effective interministerial cooperation mechanisms are required to increase policy coherence.

Research and data

There are many knowledge gaps concerning water pollution in agriculture, and more data and research are required.


Prashanth Vishwanathan / IWMI

"A sustained research and modelling effort, supported by water-quality monitoring, is needed to better understand the links between pollution causes and effects."

The contributions of crops, livestock and aquaculture to water pollution are not well known, particularly in developing countries. Quantifying these contributions is essential if national governments are to understand the full extent of the problem and to develop meaningful and cost-effective responses. The polluter-pays principle cannot be applied if the source of pollution is unclear. A sustained research and modelling effort, supported by water-quality monitoring, is needed to better understand pollutant pathways and the links between pollution causes and effects.

The pathways of, and the health and environmental risks posed by, emerging agricultural pollutants such animal hormones, antibiotics and other pharmaceuticals are growing areas of research that require more attention. For example, greater understanding is needed of the contributions of animal medicines to the increasing problem of antimicrobial resistance among pathogens.

There are opportunities for more innovation in practices and technologies to reduce the use of nutrients and pesticides on farms and the movement of pollutants from farms to sensitive aquatic ecosystems. Research is needed to evaluate policies and instruments for reducing source loads and minimizing pollution along flow paths to the sea. More work is also required to quantify the effectiveness of different approaches in reducing the economic impacts of water pollution in agriculture.

Research cannot be conducted without data. Better data are needed for understanding process and detail in specific cases and also at a broader scale to understand the pressures on and state of aquatic systems and trends in their condition. Because many indicators are subject to temporal and spatial variability, adequate monitoring programmes with appropriate sampling rates and density are key (but expensive) priorities for improvement.

Research results need to be applied if they are to be effective in reducing pollution in agriculture. It is crucial to establish information systems for transferring new knowledge and technologies to support farmers, water managers and policies. Research projects need to consider, from the conceptual stage, the specific needs of users and to engage them in the process, from knowledge generation to environmental and health outcomes.

"It is crucial to establish information systems for transferring new knowledge and technologies to support farmers, water managers and policies"

On-farm responses

On-farm practices in crop production, livestock and aquaculture are crucial for preventing pollution at the source.

In crop production, management measures for reducing the risk of water pollution due to organic and inorganic fertilizers and pesticides include limiting and optimizing the type, amount and timing of applications to crops. Establishing protection zones along surface watercourses, within farms and in buffer zones around farms have been shown to be effective in reducing pollution migration to water bodies. The storage and disposal of pesticide waste and empty containers need to follow safety guidelines. Also, efficient irrigation schemes will reduce water return flows and therefore can greatly reduce the migration of fertilizers and pesticides to water bodies (Mateo-Sagasta and Burke, 2010). Contour ploughing and restrictions on the cultivation of steeply sloping soils are measures for reducing soil erosion (US EPA, 2003). Conservation agriculture has also proved very effective in erosion control.

Manure management is one of the main concerns in livestock production. Manure needs to be stored, treated, handled and disposed of – or preferably reused – safely. Manure treatments include composting and anaerobic fermentation, which can produce valuable organic fertilizers and soil conditioners. Intensive livestock operations such as feedlots that concentrate livestock need to be managed as point sources of pollution and should follow specific national regulations. The use of feed additives, hormones and medicines should also adhere to national standards and international guidelines. In extensive livestock systems, overgrazing should be avoided to reduce land degradation and erosion.

"Efficient irrigation schemes will reduce water return flows and therefore can greatly reduce the migration of fertilizers and pesticides to water bodies"

Aquaculture farms should adopt good management practices that protect the surrounding aquatic environment, such as establishing a suitable production biomass based on the carrying capacity of the water body; avoiding excess feed by standardizing feed inputs; using fish drugs correctly and avoiding prohibited drugs; removing, treating and disposing of excessive nutrients in fishponds; and promoting integrated multitrophic aquacultural systems in which the waste of one species serves as a food source for another.

Off-farm responses

It is clear that the most effective way of mitigating pressures on aquatic ecosystems and on rural ecosystems more generally is to avoid or limit the export of pollutants from where they are applied: the costs of mitigation increase greatly once pollutants are in an ecosystem. Simple off-farm techniques, such as the construction of riparian buffer strips or constructed wetlands, can cost-effectively reduce loads entering surface water bodies. The remediation of contaminated waters such as lakes and aquifers is a long-term and expensive undertaking and in some cases may not even be feasible.

Buffer strips are a well-established technology. Vegetated filter strips at the margins of farms and along rivers are effective in decreasing concentrations of pollutants entering waterways. In agriculture and forestry, buffer zones usually comprise strips of vegetation that act as filters for sediment and their attached pollutants. Buffer strips can also perform other functions, such as stream shading, carbon sequestration, biomass production, channel stabilization, water purification and the provision of terrestrial and stream habitats, and provide cultural and recreational services.

Constructed wetlands have been employed mainly to treat point-source wastewater, including urban and agricultural stormwater runoff. Such wetlands can also be used to treat agricultural drainage and remove sediments, nutrients and other pollutants.

The risks associated with brackish and saline agricultural drainage (return flows) need to be managed. Water management options include minimizing drainage by conserving water, treating drainage water (e.g. via evaporation ponds), and reuse (brackish and saline drainage water can be reused downstream directly or blended with freshwater). Such approaches require planning at the watershed scale to adapt agricultural practices and crops to increasing salt content at different cycles of reuse, which may include the production of prawns and fish using brackish or saline waters.

Integrated aquaculture–agriculture–forestry systems in which crops, vegetables, livestock, trees and fish are managed collectively can increase production stability, resource-use efficiency and environmental sustainability. Integrated farming ensures that waste from one enterprise becomes inputs to another, thereby helping to optimize the use of resources and reduce pollution.

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I7754EN/1/08.17