SOLAW TR08

Agriculture and water quality interactions: a global overview

SOLAW Background Thematic Report - TR08

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Abbreviations and acronyms

As	Arsenic
Ca^{2+}	Calcium ion
CA	Conservation Agriculture
Fe	Iron
g	Gram
GAP	Good agricultural practices
GLADIS	Global Land and Water Degradation System
ha	hectare
IPNM	Integrated plant nutrition management
IPM	Integrated pest management
IRBM	Integrated River Basin Management
IWRM	Integrated Water Resource Management
kWh	Kilo Watt hour
LADA	Land degradation of drylands
mg	Milligram
Mg^{2+}	Magnesium ion
N	Nitrogen
Na^{+}	Sodium ion
RO	Reverse osmosis
s	Second
US EPA	United States Environmental Protection Agency
µg	Microgram
UNEP	United Nations Environmental Programme
WHO	World Health Organization

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Executive summary and main messages

Water quality and agriculture interactions are many and complex. The development of large irrigation schemes has been an important contributor to global food security, particularly in arid areas, but it has also been associated with land and water salinity problems. Both, expansion and intensification of agriculture have led to an increasing use of fertilizers and pesticides that, when not well managed, has degraded the water quality of rivers, lakes and marine water bodies. Intensification of livestock farming systems is a case in point: concentrating inputs increases the potential transmission of pollution from both animal waste and fodder production and, if not managed or regulated well, eutrophication of freshwater bodies can easily result. At the same time, such is the level of water scarcity and pollution that millions of farmers worldwide are driven to irrigate with marginal quality water such as wastewater from urban areas or saline agricultural drainage water. Minimizing both the production and food safety risks and, at the same time, maximizing benefits when using such water is an enormous challenge. Additionally, concerns about the use of naturally occurring arsenic-laden groundwater in agriculture are growing and, therefore, this emerging issue will need special attention. These are all examples of the complex interactions between agriculture and water quality that are systematically analysed in this report.

Agricultural induced water salinization

Salinity is the most important criterion for evaluating the quality of irrigation water because of the potential crop yield reductions that can result from the use of saline water which inhibits water uptake by plants.

Agricultural practice tends to induce accumulation of salt in land and water. Salts accumulated in soils can be mobilized by irrigation practice through the modification of water circulation across land. In addition pumping of groundwater can induce saline intrusion in coastal aquifers or the migration of low quality water from underlying aquifers. Major soil and water salinity problems have been reported in large irrigation schemes in China, India, Argentina, the Sudan and many countries in Central Asia, where more than 16 million ha of irrigated land are salinized through the combination of these processes. Globally, 34 million ha (11 percent of the irrigated area) are estimated to be affected by some degree of salinity.

Leaching and drainage are required to maintain the salt balance in the soil profile and to sustain crop yields in arid areas, but this drainage needs to be carefully managed to prevent salinization of water bodies. Some drainage water management options include minimizing drainage by conserving water, reuse of drainage water, safe disposal or treatment of drainage water.

Another crucial issue in coastal plains and islands is the prevention of saline intrusion induced by groundwater pumping. Two main approaches taken in dealing with this problem are to: (i) reduce groundwater abstraction in coastal areas; and (ii) actively control the freshwater-saline interface by injecting freshwater.

Water pollution from agriculture

The most important water pollution problems related to agriculture are: (i) excess nutrients accumulating in surface and coastal waters that cause eutrophication, hypoxia and algal blooms; (ii) accumulation of nitrates in groundwater; and (iii) pesticides accumulated in groundwater and surface water bodies.

Water pollution caused by nutrients (particularly nitrate) and pesticides has increased as intensive farming methods have proliferated, such as increased use of chemical fertilizers and higher concentrations of animals in smaller areas. Sources of pollution are generally diffuse but others can be concentrated (e.g. slurry management under zero grazing).

The 1980s saw a progressive worsening of water quality owing to the growth of intensive livestock farming (chickens, pigs) in areas that were already saturated, and of intensive crop-growing involving the use of chemical weedkillers and over fertilization. Developed countries have had major problems of water pollution from agriculture and trends indicate that intensified farming systems and agrochemical consumption are being extended in emerging economies.

The control of water pollution from agriculture clearly needs to occur within broader integrated water resource management frameworks that ensures linked land water use together with re-use management. Specific actions need to be carried out by polluters and implemented at the relevant scales (e.g. national, regional, municipal, local, project-level). Improved agricultural practices to minimise environmental impacts include integrated plant nutrient management, integrated pest management, conservation agriculture and livestock waste management. In addition, sustained regulation and water quality monitoring programmes at all scales are essential for planning and assessment.

Use of treated and untreated wastewater in agriculture

Population growth and rapid urbanization are increasing pressure on fresh water resources. The lack of acceptable quality water and a high level of local water demand is leading to increased water scarcity and stress and is consequently driving the use of non-conventional waters, such us treated or raw wastewater.

Wastewater use for irrigated agriculture is especially important in urban and peri-urban areas where it can serve as a new source of water and fertilizer if it has been properly managed to minimize environmental and health risks.

The resulting schemes for wastewater use can be heterogeneous, but common patterns can be detected in different countries:

- Lack of quality water and poverty driving untreated wastewater use in urban and peri-urban agriculture is a common pattern in Sub-Saharan Africa and other poor regions where there is no economic capacity to afford conventional sanitation and wastewater treatment facilities. This poses health, environmental and agriculture risks if no additional measures are applied.
- Water scarcity together with health and environmental protection are the main drivers for reclaimed wastewater use in high-income countries. This is a common pattern in countries such as Israel, Spain, Australia or the United States (California and Florida) where highly effective sanitation and treatment technology is used in planned reclamation facilities. This is a costly approach but risk is reduced almost to zero.
- Water scarcity driving treated wastewater use in emerging (middle income) countries is a common pattern in areas where low cost technologies are applied to provide partially treated wastewater for irrigation. This approach poses moderate risks to health, the environment and agriculture yield.

A robust policy and institutional framework needs to be in place to maximize benefits and minimize the risks related to the use of wastewater for irrigation. These frameworks are lacking in many countries, where wastewater use for agriculture takes place. Public institutions (health, agriculture, water) responsibilities and jurisdictions need to be clear and coordination mechanisms are necessary.

Cost effective and appropriate wastewater treatment suited for the end use of wastewater is fundamental. In most developing countries wastewater treatment is not economically feasible in the short term and interim solutions may be needed to protect farmers and public health. In these countries affordable and easily adoptable risk management strategies are preferable. Adopting multiple-barrier approaches can reduce human and crop exposure to toxic compounds and pathogens.

In addition farmers need to be provided with specific guidelines to support production and access to markets and effective dissemination and education campaigns to facilitate the adoption of such guidelines are critical.

Use of saline or desalinated water in agriculture

Salinized and sodic drainage water and groundwater are often used for irrigation. Use of this water poses agriculture and environmental risks owing to soil salinization and water quality degradation downstream.

Although no global assessment exists, the use of saline or sodic water is a common practice in many countries such as Bangladesh, China, Egypt, India, Iran, Pakistan, Syria, Spain and the United States, notably for the irrigation of salt-tolerant plants and trees, but also conventional grains and forage.

When managing salinity it is important to bear in mind that many land and irrigation areas have varying levels of tolerance to increases in salinity. Therefore, salinity needs to be considered in the context of the particular asset at risk and the value of that asset. Salinity risk assessment should be carried out to determine the intensity of the measures to apply and the methods to follow. In areas identified as having a high hazard level, a good salinity monitoring programme should be developed. In addition, actions aiming to prevent further salinization of land and water or to remedy saline or sodic soils should be implemented. These actions include more efficient irrigated agriculture, effective drainage measures, crop selection or treatment of saline drainage before reuse.

Desalination of saline groundwater and brackish drainage water have arisen as one of the options available to cope with the problem of water salinization, in addition it is used for augmenting freshwater resources when seawater is desalinated. Even when the technology presents interesting opportunities, the main constraint to widespread use of desalinated water for agriculture is high energy consumption and associated costs.

Use of arsenic laden waters

Naturally occurring arsenic in groundwater has been reported in more than 20 countries worldwide and, in many, shallow groundwater is used for drinking and irrigation. Natural arsenic in groundwater at concentrations above the drinking water standard of 10 µg/litre is not uncommon, and the realization that water resources can contain insidious toxic concentrations of naturally-occurring chemical constituents, such as arsenic, is fairly recent and increasingly urgent.

First estimates of arsenic toxicity (arsenosis) from drinking water, causing skin lesions and various types of cancers, indicate about 130 million people are impacted. Sources of arsenic that have been created by people, such as mineral extraction and processing wastes, poultry and swine feed additives, pesticides and highly soluble arsenic trioxide stockpiles are not uncommon and have caused the contamination of soils and groundwaters. Arsenic accumulation in the food chain (e.g. arsenic transfer in rice in Asia) is a major concern that needs to be tackled globally and, most importantly, the scale of the problem needs to be better quantified.

Finally, management options are being developed and successfully tested to prevent and mitigate Arsenic (As)-contamination of agricultural land. For example strategies for management of arsenic that would enable continuing rice production in polluted areas include: (i) growing rice in an aerobic environment where As is adsorbed on oxidized Fe (iron) surfaces and is largely unavailable to rice; (ii) switching from As-contaminated shallow groundwater to non-contaminated surface or deep groundwater to avoid further build up of soil As; or (iii) identification or development of arsenic tolerant rice varieties, where arsenic uptake is also low.

1. Introduction

There are many and very complex agriculture and water quality interactions. In this paper we explore the main water quality impacts from agriculture, including livestock, and the use of marginal quality water, also in agriculture. While linkages between water quality and aquaculture or forestry are also relevant, these subjects are better covered in other FAO publications (e.g. FAO 2008a or FAO 2001) and are out of the scope of this report.

Section 2 explores the role of agriculture as a driver of salinization and pollution: Many large irrigation schemes around the world, especially in arid areas, have been suffering from salinization of land and water. Globally 34 million ha are now impacted. Expansion and intensification of agriculture have led to increasing use of fertilizers and pesticides which has resulted in higher crop productivity. If not well managed, however, fertilizers and pesticides can degrade the water quality of rivers, lakes and marine water bodies. In addition, intensification of livestock farming systems is increasing pressure on water bodies. Section 2 reviews the chain: drivers, agriculture related pressures and state of water bodies at the global scale. In addition, remedial actions are proposed, including policy recommendations, that take the relevant socio-economic context into account.

Section 3 focuses on the use of marginal quality water, such as wastewater from urban areas or saline agricultural drainage water, as millions of farmers worldwide often have no other alternative but to irrigate with these waters. Minimizing risks and, at the same time, maximizing benefits when using such water is an enormous challenge that needs to be addressed. In addition, concerns about the use of arsenic-laden water in agriculture are growing and, therefore, this emerging issue needs special attention. Section 3 reviews the main factors driving the use of marginal quality water for agriculture and provides an overview of the use of such water worldwide. Moreover key considerations are outlined to guide policy.

2. Water quality impacts from agriculture

The main water quality problems associated with agriculture worldwide are salinization and nutrient and pesticide pollution. Salinization is commonly cited as the most widespread groundwater quality problem and as having the greatest environmental and economic impacts (Morris *et.al.,* 2003). On the other hand eutrophication, a result of high nutrient loads (mainly nitrogen and phosphorus), is considered to be the prevailing water quality problem for surface water (UN-Water, 2009). Other pollutants originating in agricultural activities include pesticides, oxygen-demanding substances and sediments.

2.1 Salinization of water resources in irrigated areas

2.1.1 Problem statement, concepts and definitions

Salinity is the most important criterion for evaluating irrigation water quality (Ghassemi, *et al.*, 1995). High salt concentrations prevent the uptake of water by plants causing crop–yield reductions. This occurs when salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in water stress for a significant period (FAO, 1994). If water uptake is appreciably reduced, the plant slows its rate of growth. The plant symptoms are similar in appearance to those of drought.

Soil salinization in its early stages of development reduces soil productivity, but in advanced stages it kills all vegetation and consequently transforms fertile and productive land to barren land.

When speaking of water quality, sodicity is also a very important variable. The term refers to the presence of a high proportion of sodium (Na^+) ions relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in soil or water. Sodicity degrades soil structure by breaking down clay aggregates, which results in more easily eroded soil that is less permeable to water, which then reduces plant growth.

Irrigating with saline or sodic water generally results in enhanced salinity or sodicity in soil water unless proper irrigation measures are applied. These measures include applying irrigation water in excess of crop requirements to leach the salts from the soil (leaching factor) and favouring the drainage of saline water through well-designed drainage systems.

Waterlogging, which is one of the consequences of land sodicity and one of the precursors of land salinization, damages plant growth. There must be a balance between the amount of air and water in the soil for healthy growth of the plant. If the soil is waterlogged, the plant's growth will be damaged and its production will be adversely affected.

Environmental and agricultural damage caused by salinity, sodicity and waterlogging may imply very severe economic and social damage, therefore well designed policies need to be developed for prevention and remediation.

2.1.2 Causes and drivers of water salinization

There are different causes, both natural and human, that can induce accumulation of salt in soils and water resources. Natural salinity refers to the 'primary' salinity that was present prior to the development of land for agriculture, and human-induced salinity refers to the 'secondary' salinity often caused by land-use change.

Natural salinization of land and water is closely related to the long-term accumulation of salts in the soil profile and, subsequently, in groundwater, but it could occur as a result of the one-time submergence of soils under seawater (Ghassemi, *et al.*, 1995).

Salts accumulated in soils could be mobilized and cause salinization of water bodies. The main cause for this salt mobilization is irrigation. Application of leaching fractions for soil-clearing entails the discharge of saline effluents from drainage schemes in irrigated areas. In addition, excessive irrigation can raise water tables from saline aquifers and this can increase seepage of saline groundwater into water courses and increase their salinization. Intrusion of saline seawater into aquifers is another important cause of salinization of water resources in coastal areas. This intrusion is frequently the result of excessive groundwater extractions for agriculture. Excess mineral fertilization in agriculture also plays a role in the increase of salt content in water resources.

Other human factors that can be locally important for water salinization is the discharge of saline water to rivers from industries and mining activities. In addition, periodic application of de-icing agents in snow-belt regions of industrialized countries contributes to the accumulation of salt in the soil and water.

2.1.3 Extent of salinization: Global overview

In almost all countries where land salinization is a major problem, it is accompanied by water salinization. Table 1 shows the regional distribution of agricultural land salinized by irrigation and indicates that, globally, 34 Mha are now impacted.

Major problems have been reported in Pakistan, China, United States, India, Argentina, Sudan and many countries in Central and Western Asia. (AQUASTAT and Ghassemi, *et al*., 1995). Countries shown in Table 2 accumulate 90% of the area salinized by irrigation.

Figure 1 represents the spatial distribution of land under irrigation which is affected by some degree of salinization. It was produced by combining FAO AQUASTAT country statistics regarding irrigated areas affected by salinization with spatial information on irrigated areas where precipitation is not sufficient to leach away salt residues that are built up in the soil due to irrigation. It was assumed that the risk of salinization of irrigated areas can occur only in areas with an Aridity Index lower than 0.65 (where the Aridity Index is defined as Yearly Precipitation divided by Yearly Reference Evapotranspiration).

2.1.4 Actions to prevent water salinization from agriculture.

Leaching and drainage are required to maintain salt balance in the soil profile and to sustain crop yields in arid areas (FAO, 2007b). The salinity of drainage water might be up to 50 times higher than irrigation water and its disposal can increase the salinity of receiving water bodies. The challenge is to minimize environmental impacts on ecosystems linked to these water bodies, as well as the economic impacts on the subsequent activities (e.g. agriculture), using this water.

TABLE 1: AREA SALINIZED BY IRRIGATION PER REGION

Region	Million ha
South Asia	10.30
East Asia	6.70
Western Asia	6.12
Northern America	5.34
Central Asia	3.21
Southern America	0.95
Sub-Saharan Africa	0.68
Northern Africa	0.68
Australia and New Zealand	0.20
Total	34.19

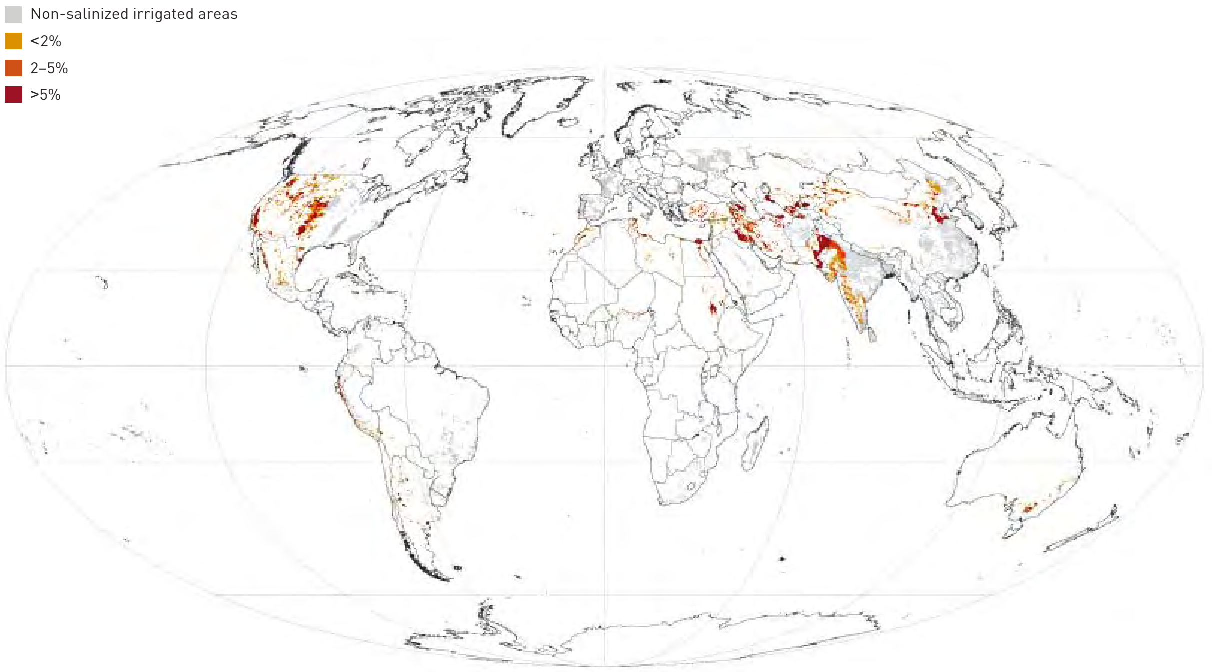
Source: AQUASTAT, different years.
** Regions based on country groupings used in SOLAW.*

TABLE 2: COUNTRIES WITH THE LARGEST AREAS SALINIZED BY IRRIGATION

Country	Million ha
Pakistan	7.00
China	6.70
United States	4.90
India	3.30
Uzbekistan	2.14
Iran (Islamic Republic of)	2.10
Iraq	1.75
Turkey	1.52

Source: AQUASTAT different years and Ghassemi 1995.

FIGURE 1: PROPORTION OF LAND SALINAZED DUE TO IRRIGATION



Source: FAO

Until 20 years ago there were few constraints to the disposal of drainage water from irrigated lands. One of the principal reasons for increased constraints on drainage disposal is to protect the quality of receiving waters for downstream uses and to protect the local environment and ecology. Now, many developed and developing countries carry out drainage water management practices. These practices can be grouped as follows:

- water conservation;
- drainage water reuse;
- drainage water disposal; and
- drainage water treatment.

Each of these options may impact hydrology and water quality in an area. Interactions and trade-offs occur when more than one option is applied.

Planners, decision-makers and engineers need a framework to help them select from among the various options and to evaluate their impact and contribution towards development goals. Moreover, technical expertise and guidelines on each of the options are required to enable improved assessment of the impact of the different options and to facilitate the preparation of drainage water management plans and designs. FAO provides guidelines to plan and design land drainage systems (FAO, 2007b and FAO 2005), at the same time, to protect water resources from the negative impacts of the disposal of agricultural drainage water (FAO, 2002).

The environmental and economic hazards must be considered carefully and, if necessary, mitigating measures taken. If possible, drainage must be limited to wet seasons only, when the salty effluent inflicts the least harm. In regions with pronounced dry and wet seasons, the drainage system may be operated in the wet season only and closed during the dry season. This practice of checked or controlled drainage saves irrigation water.

Another crucial issue in coastal plains and islands is the prevention of saline intrusion induced by groundwater pumping. Two main approaches taken to deal with this problem are: (i) reduction of water extraction from groundwater in coastal areas; and (ii) the creation of saltwater intrusion barriers by injecting water into aquifers.

2.2 Agriculture pollution of water resources

Agriculture is by far the greatest water user in the world and consequently a major cause of water pollution. Agricultural pollution is commonly non-point source, however, agricultural operations sometimes include identifiable point source discharges, particularly for concentrated livestock operations. The main pollutants from agriculture are excess nutrients and pesticides.

2.2.1 Problem statement, concepts and definitions.

Excess nutrients causing eutrophication, hypoxia and algal blooms in surface water bodies and coastal areas is the main water quality problem globally (UN-Water, 2009). It has been suggested that the planetary boundaries, or upper tolerable limit, for changes to the global nitrogen cycle (Rockstrom *et al*., 2011) and for freshwater eutrophication has been already crossed (Carpenter and Bennet, 2011). Major nutrient sources affecting water include agricultural runoff and domestic sewage, industrial and mining effluents as well as atmospheric inputs from the burning of fossil fuels. In a comparison of domestic, industrial, and agricultural sources of pollution from the coastal areas of Mediterranean countries, agriculture was the leading source of nutrients (UNEP, 1996). High-nutrient loads (mainly phosphorus and nitrogen) substantially harm beneficial uses of water.

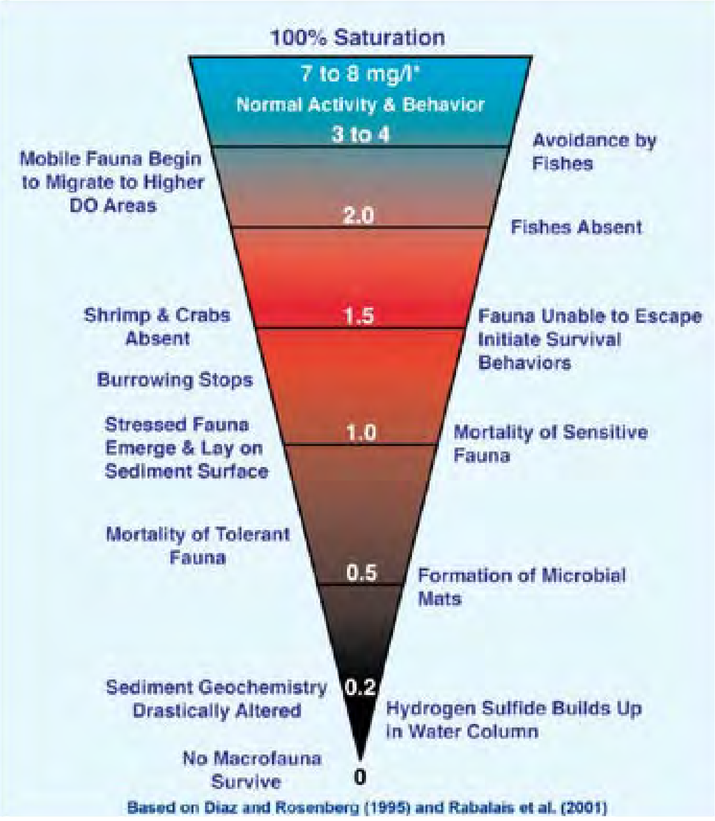
Nitrogen and phosphorus are factors that limit life in aquatic ecosystems. Eutrophication is excessive nutrient accumulation (e.g. nitrogen concentrations higher than 5 mg/litre), which generally promotes excessive plant growth and decay. Normally, simple algae and plankton are favoured over other more complicated plants and water becomes cloudy, shady and coloured.

The process of decay consumes dissolved oxygen in the water creating hypoxic conditions and harming oxygen-consuming fish and shellfish. These effects on fauna are shown in Figure 2. Excessive nutrient inputs can also cause harmful algal blooms. Cyanobacteria, also known as blue-green algae, have increased in fresh waters and coastal areas such as the East China Sea in recent decades (UN-Water, 2009). The toxins produced by the excessive algae can cause poisoning of fish, shellfish and even humans. Global warming may exacerbate this problem, since cyanobacteria have a competitive advantage over other types of algae at higher temperatures.

Excess nitrogen (N) driving accumulation of nitrates in groundwater is another crucial issue. Nitrate is a soluble compound that can be easily leached from soil by deep percolation to aquifers. In many irrigated areas concentrations of nitrate in underlying groundwater are greater than the World Health Organization (WHO) standards for drinking water (50 mg/litre). This is directly related to the intensive and improper use of mineral fertilizer and manure for agriculture, sometimes exceeding crop–nitrogen demand. This relation between agriculture intensification and nitrate pollution of groundwater is illustrated in Figure 3, which shows that nitrate in groundwater under intensive cash-crop cultivation was higher than under mixed farming areas, extensive coconut cultivation and uncultivated areas in Sri Lanka.

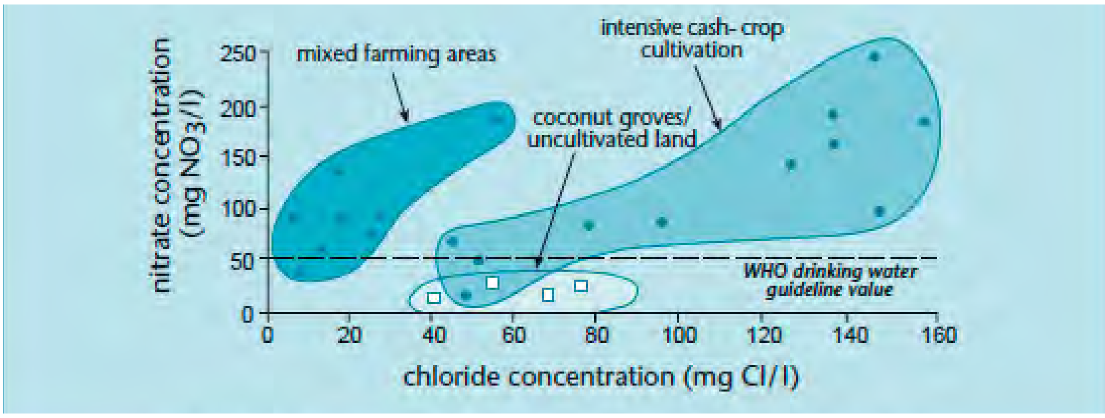
Pesticide accumulation in groundwater and surface water bodies, especially lakes and wetlands, is an increasing concern. All pesticides are designed to be sufficiently toxic and persistent to reduce populations of the weed, insect or fungal pest they are designed to control, but they can also be toxic (poisonous) to desirable plants and animals, including people. Some pesticides are so highly toxic that very small quantities can kill a person, while exposure to a sufficient amount of almost any pesticide can make a person ill. Prior to the 1980s, there was relatively little concern that water resources, especially groundwater, could be polluted by pesticides (Morris *et al.*, 2003). However, extensive monitoring campaigns in developed countries have shown an increasing presence off such compounds in surface water and groundwater.

FIGURE 2: **CONE OF FAUNAL RESPONSE TO DECLINING OXYGEN CONCENTRATION**



Source: Based on data from Díaz and Rosenberg (1995) and Rabalais et al. (2001).

FIGURE 3: **RELATIONSHIP BETWEEN GROUNDWATER NITRATE CONCENTRATIONS AND CHLORIDE CONCENTRATIONS FOR DIFFERENT AGRICULTURAL LAND USES, KALPITIYA PENINSULA, SRI LANKA**

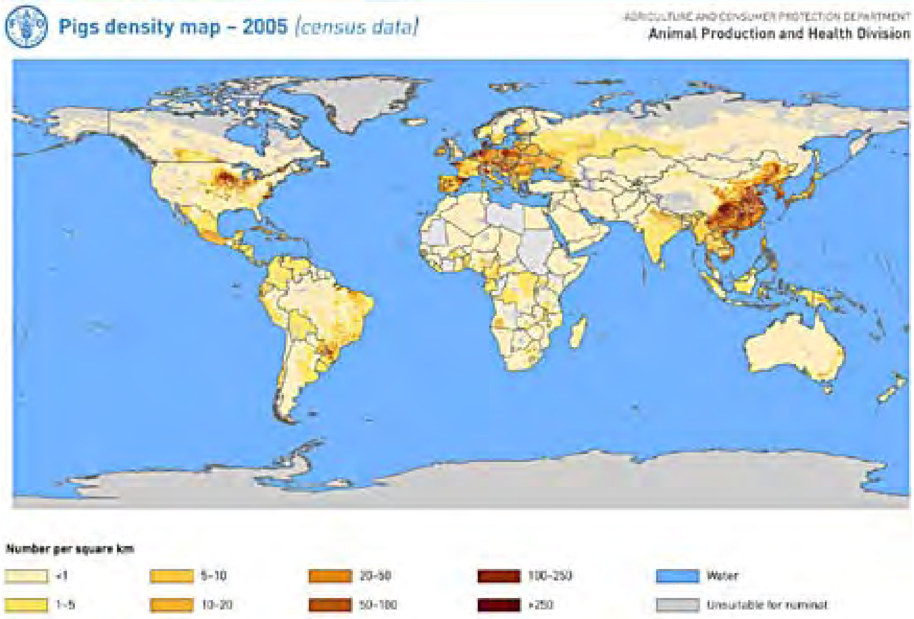


Source: from Mubarak et al., 1992

2.2.2 Drivers and causes of increasing agriculture pollution

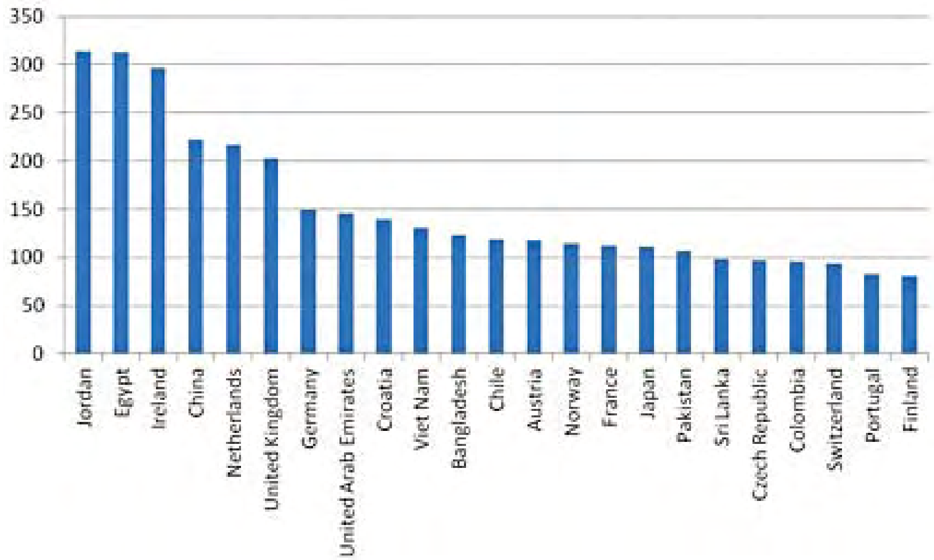
Intensification of agriculture during the second half of the twentieth century has brought enormous benefits to global food security. Agriculture productivity has been steadily increasing because of the rapid expansion of irrigation, fertilizer application and better pest control. However, intensified use of fertilizers and pesticides, and the growth of intensive livestock farming, have also had unanticipated adverse impacts on the quality of surface water resources and underlying groundwater. An indicator of this intensification process is the high concentration of pig breeding in East Asia and Europe (Figure 4) or the high consumption of mineral fertilizers per unit of cultivated area in some countries (Figure 5).

FIGURE 4: **ESTIMATED PIG DENSITY WORLDWIDE (2005)**



Source: FAO, 2007a

FIGURE 5: **AVERAGE CONSUMPTION OF MINERAL NITROGEN FERTILIZERS PER CULTIVATED LAND (ARABLE LAND AND PERMANENT CROPS) IN SELECTED COUNTRIES IN 2002 (kgN/ha)**



Source: FAOSTAT

Note: Organic fertilizers (e.g. manure) are not accounted for.

Intensified use of fertilizers has often come together with improper management and/or excessive application of nutrients. Today the link is clear between expanding and intensification of cultivated areas, increasing unit of fertilizer use and rising groundwater nitrate concentrations in developed countries. This is also of increasing concern in many emerging countries where agricultural expansion and intensification are taking place.

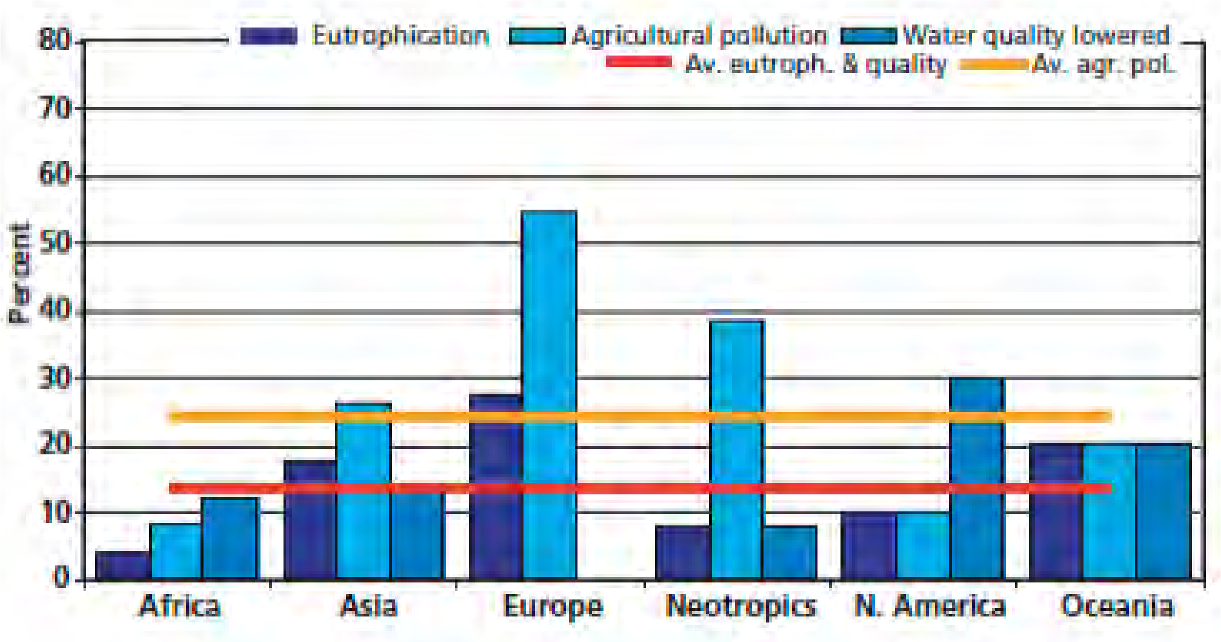
The use of pesticides has followed a similar pattern to that of nutrients with an intensified use often accompanied by improper management practices such as: (i) an improper selection of pesticides; (ii) poor pesticide storage; (iii) disposal of pesticide spray-tank washings; or (iv) landfill disposal of pesticide processing waste. So far this intensification and poor management of pesticides have primarily affected developed countries, but this is a problem that is gaining importance in developing countries, where a proper regulatory and control framework is often lacking.

2.2.3 Eutrophication and hypoxia in wetlands and coastal areas

The FAO Water Report: *Scoping agriculture-wetlands interactions* (2008b) reviewed 90 wetlands around the word and studied three different types of water quality degradation: (i) eutrophication, (ii) water quality lowered by agricultural pollution and (iii) overall lowered water quality (Figure 6). Eutrophication, regardless the driver, is a frequent trend in wetlands in Europe, Asia and Oceania. Pollution from agriculture is most severe (most frequent) in European wetlands, wetlands in Neotropics (Latin America) and Asian wetlands. Water quality degradation (regardless the source –agriculture or other-) is most pronounced for North America and Oceania. This general state change provides little insight into the origins or effects of water pollution (chemical or biochemical), however, it does indicate the presence of a water quality problem. The African cases list very few state changes for water quality/pollution, which is in line with what would be expected of the generally low (or lower) input agriculture systems.

Similarly, much of the hypoxia and anoxia in shallow coastal marine areas has developed within the last 50 years and is closely associated with anthropogenic activities. Díaz and Rabalais (2010) noted that no

FIGURE 6: PERCENTAGE OFF WETLANDS SUFFERING WATER QUALITY DEGRADATION PER REGION



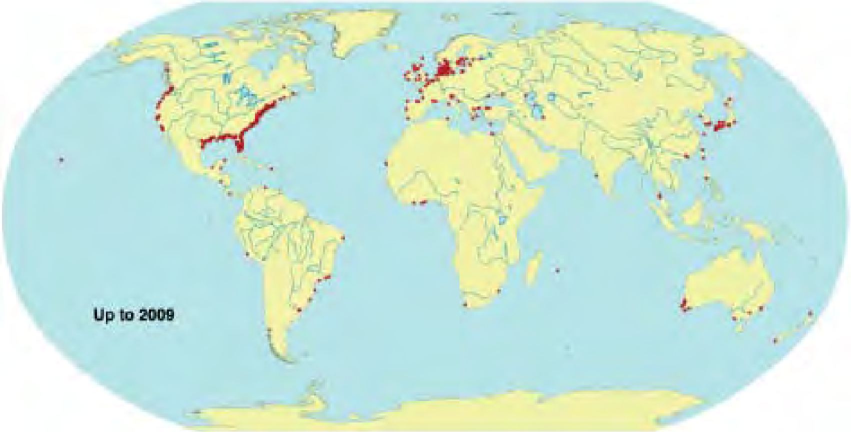
Source: FAO, 2008b

other environmental variable of such ecological importance to estuarine and coastal marine ecosystems has changed so drastically in such a short period. Over time trends have been consistent for increasing severity of duration, intensity, or extent of hypoxia in areas with long-term data, for example the northern Adriatic Sea. Currently, there are over 500 hypoxia areas associated with anthropogenic activities in the world's coastal areas covering more than 245 000 km^2 of sea bottom (Figure 7).

2.2.4 Nitrate in groundwater

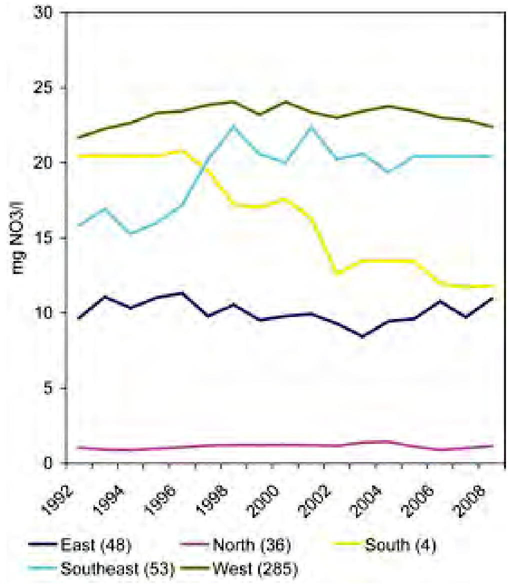
Nitrate is the most common chemical contaminant in the world's groundwater aquifers. Nitrate in groundwater has been reported as a major problem in Europe, United States and South and East Asia. In Europe, even when mean concentrations of nitrate in groundwater have remain relatively stable in the last decades (Figure 8), nitrate drinking water limit values are exceeded in around one-third of the groundwater bodies for which

FIGURE 7: GLOBAL DISTRIBUTION OF DOCUMENTED CASES OF HYPOXIA IN COASTAL AREAS RELATED TO HUMAN ACTIVITIES, RED DOTS



Source: Rabalais et al., 2010

FIGURE 8: NITRATE CONCENTRATIONS IN GROUNDWATER BETWEEN 1992 AND 2008 IN DIFFERENT GEOGRAPHICAL REGIONS OF EUROPE.



Source EEA 2008

Note: The number of groundwater bodies included per country is given in parentheses.

information is currently available (EEA, 2008). In India the occurrence of nitrate in ground water beyond national permissible limit (45 mg nitrate/l) has been reported in hundreds of districts in 21 Indian states (CWWB, 2010). In China, according to the China Geological Survey, nitrate pollution of the shallow groundwater is widespread with almost 100% of water samples containing some level of nitrate, and with 30-60% of samples containing nitrates at levels above the national standard (20 mgN/l).

2.2.5 Pesticides pollution of water resources

According to available data in FAOSTAT, the United States is currently the country consuming the largest amount of pesticides, followed by China, Colombia and Brazil. In terms of use per unit area of cultivated area, Colombia, Costa Rica and Japan are the most intensive users of pesticides (Figure 9). Consumption and intensity of pesticides use serve as indicator of how pesticides stress water bodies. Even when pesticide consumption in developing countries represents only a small proportion of the global consumption, rates of increase in pesticide consumption are now greater in some of the more rapidly developing economies than in the developed world. This increase in the amount of pesticides consumed worldwide is counteracting the effective use of new pesticide compounds at lower dose rates.

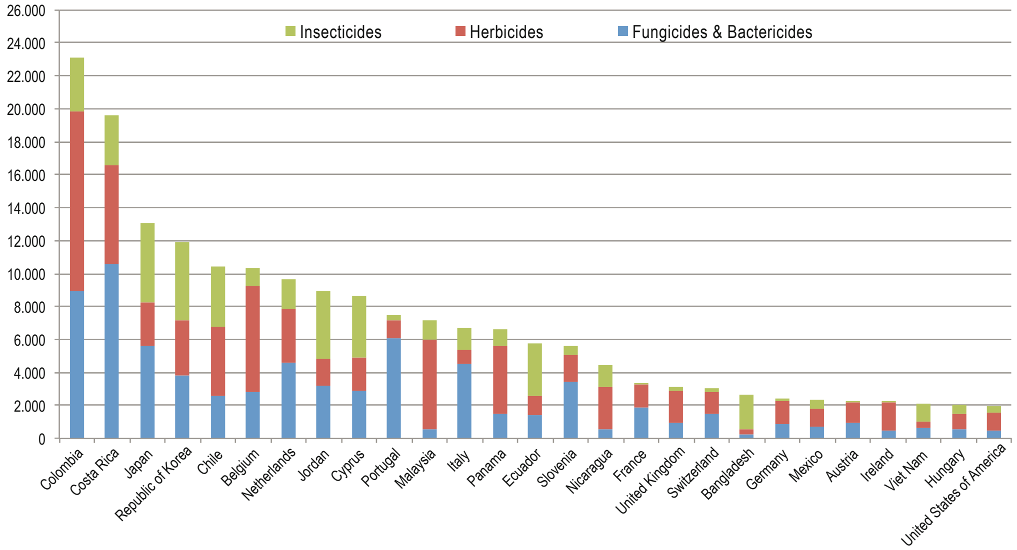
As a result of the expansion of water monitoring programmes in developed countries an increasing number of pesticides are being detected in water bodies in these countries. Table 3 shows a summary of pesticides occurring in groundwater.

2.2.6 Agriculture pollution trends

Livestock waste production and fertilizer and pesticide consumption have increased over the last 50 years worldwide, mainly because of the green revolution and especially in developed countries. Although, in the last two decades, the agrochemical consumption rate is stabilizing or even declining in some developed countries, the fast-growing developing countries are becoming the greatest users of agricultural inputs. Figure 10 shows mineral fertilizer consumption, giving trends for different regions of the world.

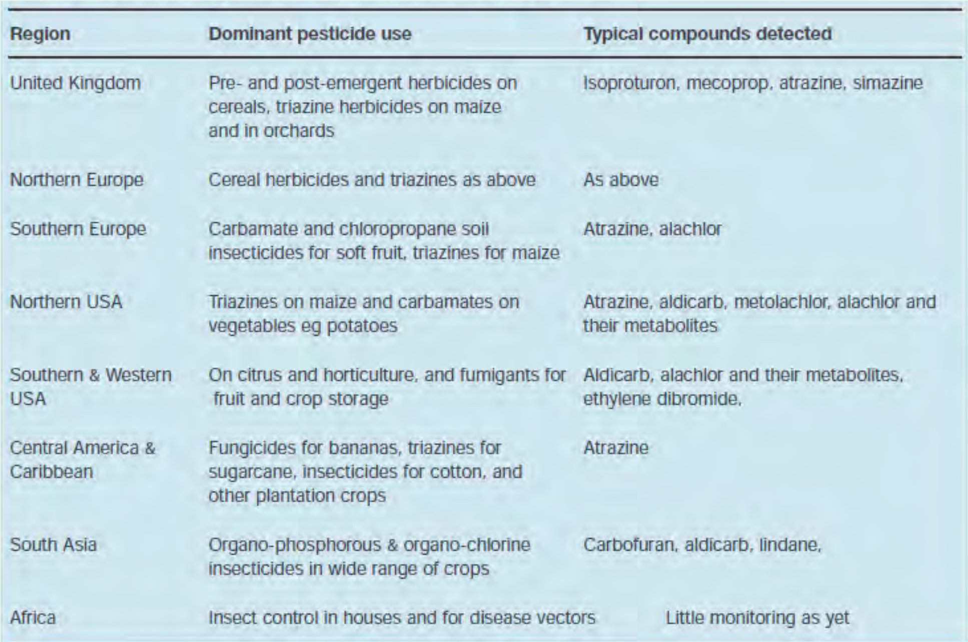
This increase in nutrient and pesticide loads on croplands has increased the transport through and accumulation in water systems. Figures 11 illustrates this evolution in nutrient transport taking nitrogen as an example.

FIGURE 9: CONSUMPTION OF INSECTICIDES, HERBICIDES, FUNGICIDES AND BACTERICIDES PER UNIT OF ARABLE LAND AND PERMANENT CROPS (G/HA). COUNTRIES WITH HIGHER INTENSITY USE OF PESTICIDES ARE SELECTED.



Source: FAOSTAT 2006, 2007 and other years for USA, Brazil and Malaysia.

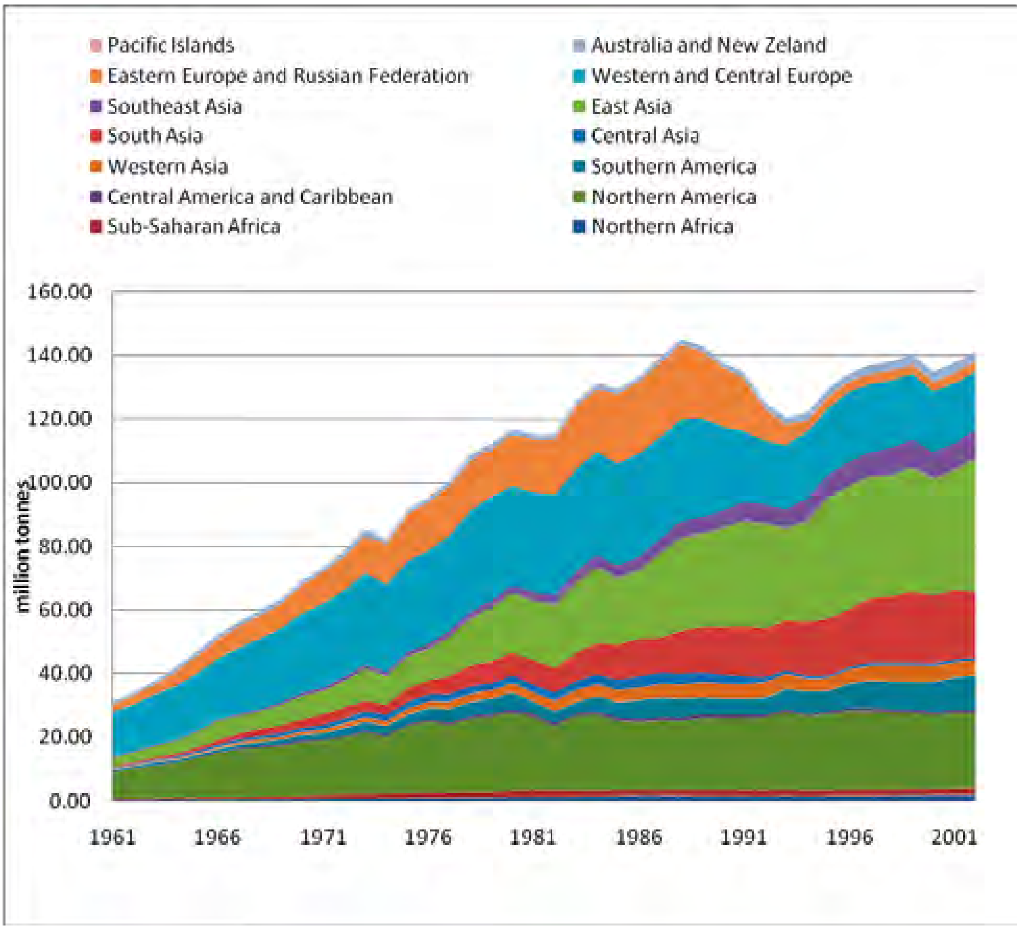
TABLE 3: DOMINANT PESTICIDES USED AND TYPICAL COMPOUNDS DETECTED IN GROUNDWATER IN SELECTED REGIONS



Region	Dominant pesticide use	Typical compounds detected
United Kingdom	Pre- and post-emergent herbicides on cereals, triazine herbicides on maize and in orchards	Isoproturon, mecoprop, atrazine, simazine
Northern Europe	Cereal herbicides and triazines as above	As above
Southern Europe	Carbamate and chloropropane soil insecticides for soft fruit, triazines for maize	Atrazine, alachlor
Northern USA	Triazines on maize and carbamates on vegetables eg potatoes	Atrazine, aldicarb, metolachlor, alachlor and their metabolites
Southern & Western USA	On citrus and horticulture, and fumigants for fruit and crop storage	Aldicarb, alachlor and their metabolites, ethylene dibromide,
Central America & Caribbean	Fungicides for bananas, triazines for sugarcane, insecticides for cotton, and other plantation crops	Atrazine
South Asia	Organo-phosphorous & organo-chlorine insecticides in wide range of crops	Carbofuran, aldicarb, lindane,
Africa	Insect control in houses and for disease vectors	Little monitoring as yet

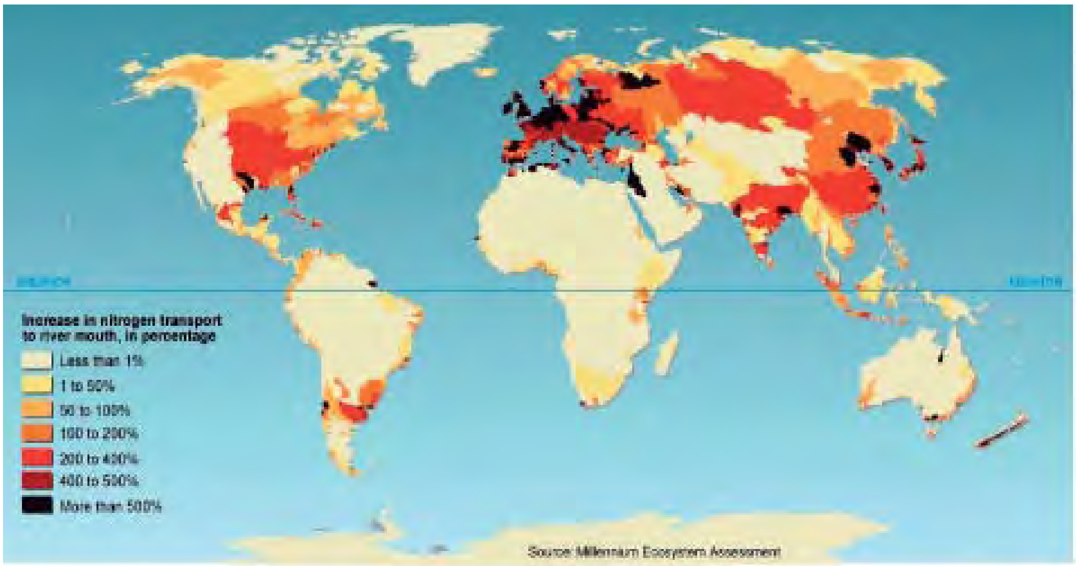
Source: Morris et al., 2003

FIGURE 10: CONSUMPTION OF MINERAL FERTILIZERS PER REGION FROM 1961 TO 2002



Source: FAOSTAT

FIGURE 11: CONTRAST BETWEEN CONTEMPORARY AND PRE-DISTURBANCE TRANSPORT OF TOTAL NITROGEN THROUGH INLAND AQUATIC SYSTEMS RESULTING FROM ANTHROPOGENIC ACCELERATION OF THIS NUTRIENT CYCLE.



Source: Millennium Ecosystem Assessment 2005

The excess of nutrient loads sometimes exceeds the capacity of natural systems to assimilate additional constituents. For example, in combination with increasing urban and industrial wastewater discharge, additional nutrient load has resulted in increasing cases of hypoxia related to human activities in coastal areas as shown in Figure 12.

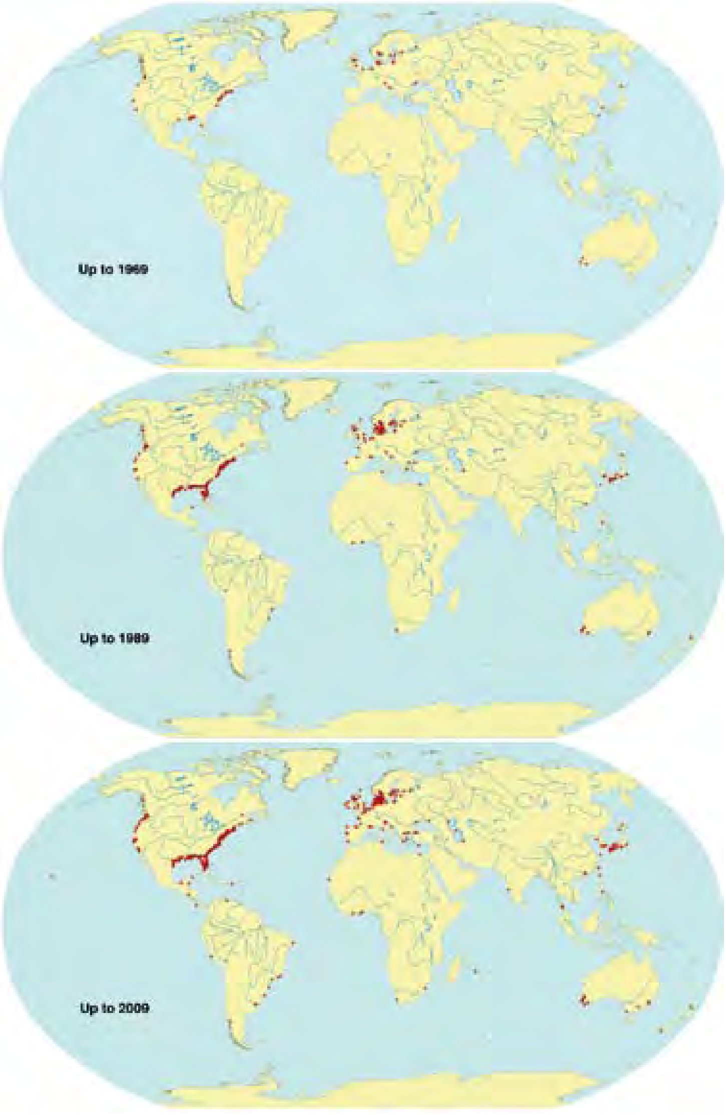
2.2.7 Remedial and preventing actions against agriculture pollution

Management to remedy pollution from agriculture should occur within broader integrated management frameworks such as Integrated Water Resource Management (IWRM) and Integrated River Basin Management (IRBM) that ensure a comprehensive overview of the problem, but specific actions need to be carried out by polluters and implemented at the relevant scales (e.g. national, regional, municipal, local, project-level).

In existing, or potential, areas that have been polluted by agriculture, strategies and action plans should include explicit analyses of a broad range of diagnosis, prevention and remedial options. The most important and comprehensive measure taken to minimize agriculture pollutant loads to water systems has been the implementation of good agricultural practices (GAP) including integrated plant nutrient management (IPNM) and integrated pest management (IPM) for the rational use of pesticides, fertilizers and proper livestock waste management practices. For these GAP to be adopted by farmers the proper policies need to be designed including regulations and education, dissemination and communication policies. FAO has produced extensive information (plant nutrition bulletins, irrigation and drainage papers, etc.) and offers important services for GAP and IPNM (available at: http://www.fao.org/prods/GAP/index_en.htm and http://www.fao.org/agriculture/crops/core-themes/theme/spi/it/). Prevention and disposal of obsolete pesticides deserves special attention since often stockpiles of old pesticides are poorly stored and toxic chemicals leak into the environment (more information in http://www.fao.org/ag/AGP/AGPP/Pesticid/Disposal/guides_en.htm).

Sustained monitoring programmes at all scales are essential. Agriculture pollution prevention policies require abundant and quality data. Water quality data are used to characterize waters, identify trends over

FIGURE 12: EVOLUTION OF DOCUMENTED CASES OF HYPOXIA RELATED TO HUMAN ACTIVITIES, RED DOTS. THE NUMBER OF HYPOXIC AREAS IS CUMULATIVE FOR THE SUCCESSIVE TIME PERIODS.



Source: Rabalais et al., 2010

time, identify emerging problems and help direct pollution control efforts to where they are most needed. In addition, where pollution control programmes are already taking place, data analysis allows assessment of the effectiveness of the programme. A good water quality monitoring programme should include a proper selection of: i) sampling sites; ii) sampling stations; iii) parameters to be monitored; and iv) the frequency and timing of sampling. Complete guidance on how to design and implement freshwater quality studies and monitoring programmes can be found in UNEP/WHO 1996. In addition, complementary information and statistics are needed on pressure indicators from agriculture such as type and extent of fertilizers and pesticides used.

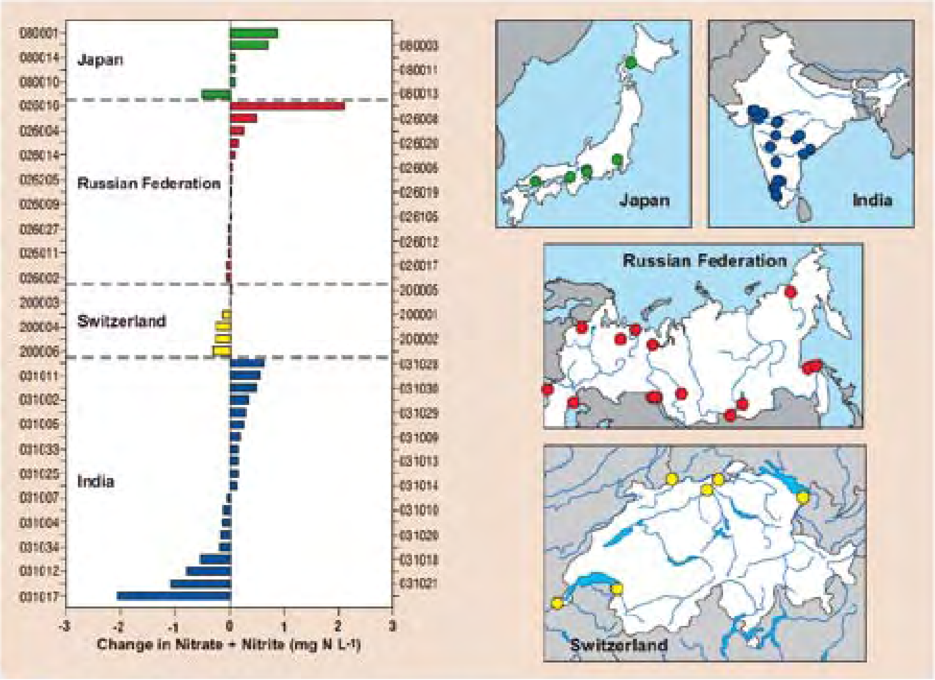
There are examples from around the world of successful policies that reduce pollution loads from agriculture. Rabalais *et al.* 2010 reported improvements in oxygen depletion conditions in many smaller systems worldwide and other examples of diminished symptoms of eutrophication through reductions in nutrient loadings (Figure 13). The UNEP-GEMS *Water quality outlook* showed changes in median nitrate concentrations in rivers between the early 1980s and the early 2000s in Japan, the Russian Federation, Switzerland and India

(Figure 14). Improvements (measured as decreases) in nitrate concentrations could be detected at most Swiss river monitoring stations and about half of the Indian river stations, whereas nitrate increased or remained the same in most Japanese and Russian river stations. The improvements in nitrate concentrations are likely to be the result of local and regional efforts to reduce pollutant loads into rivers and lakes (UNEP-GMES 2004).

FIGURE 13: LOCATION OF 38 SYSTEMS THAT HAVE RECOVERED FROM HYPOXIA (GREEN CIRCLES), PRIMARILY THROUGH MANAGEMENT AND REDUCTION OF NUTRIENT LOADS. ALL SITES ARE IN NORTHERN EUROPE AND THE UNITED STATES, EXCEPT THE BLACK SEA AND LAKE TUNIS IN THE MEDITERRANEAN SEA. BLACK DOTS ARE SYSTEMS THAT REMAIN HYPOXIC.

Source: Rabalais et al., 2010

FIGURE 14: CHANGE IN MEDIAN COMBINED NITRATE AND NITRITE CONCENTRATIONS AT RIVER MONITORING STATIONS BETWEEN 1980-1984 AND 2000-2004. POSITIVE VALUES INDICATE AN INCREASE AND NEGATIVE VALUES INDICATE A DECREASE IN COMBINED NITRATE AND NITRITE CONCENTRATIONS OVER TIME. STATION IDENTIFIERS ARE SHOWN ON THE VERTICAL AXIS.



Source: UNEP-GMES 2004

3. Marginal quality water use for agriculture

Currently, irrigation using marginal-quality water is a common practice for millions of farmers worldwide. Often these farmers do not have access to an alternative source of clean water. There are different types of marginal-quality water but the most important, in terms of number of users, are wastewater from domestic and other urban activities and saline or sodic agricultural drainage water and groundwater. Additionally, concerns about the use of arsenic-laden water in agriculture are growing. This emerging issue needs special attention.

3.1 Urban wastewater use in agriculture

3.1.1 Problem statement, concepts and definitions

As pressure on water resources intensifies, the conservation of fresh water through use of non-conventional waters, such us (treated) wastewater becomes an increasingly relevant option. Wastewater use for irrigated agriculture is especially important, particularly in urban and peri-urban areas (Figure 15). This section reviews the status and trends of wastewater use in agriculture and provides policy and management recommendations to maximize benefits and minimize the risks of such a use.

Even when no commonly shared terminology is used to refer to the different types of wastewaters and their use, Box 1 gives the definitions of terms used in this report, which are often used by many authors.

FIGURE 15: DIFFERENT SCHEMES OF DIRECT USE OF TREATED OR UNTREATED WASTEWATER

Source: FAO, 2010

BOX 1: DEFINITIONS

Types of wastewater

The term wastewater, as used in this report, include raw and diluted wastewater.

Urban wastewater is usually a combination of one or more of the following:

- Domestic effluent consisting of black water (excreta, urine and associated sludge) and grey water (kitchen and bathroom wastewater).
- Effluent from commercial establishments and institutions, including hospitals.
- Industrial effluent where present.
- Storm water and other urban runoff.

Treated wastewater is wastewater that has been processed by a wastewater treatment plant and that has been subjected to one or more physical, chemical, and biological processes to reduce its pollution or health hazard.

Reclaimed (waste) water or recycled water is treated wastewater that can officially be used under controlled conditions for beneficial purposes, such as irrigation.

Types of wastewater use in agriculture

- Direct use of untreated wastewater from a sewage outlet occurs when it is directly disposed of on land where it is used for cultivation.
- Indirect use of (un)treated urban wastewater occurs when water from a river receiving (un)treated urban wastewater is abstracted by farmers downstream of the urban centre for agriculture. This happens when cities do not have a comprehensive sewage collection network and drainage systems are discharging collected wastewater into rivers.
- Direct use of treated wastewater occurs when wastewater has undergone treatment before it is used for agriculture or other irrigation or recycling purposes.
- Planned use of wastewater refers to the conscious and controlled use of wastewater either raw (direct) or diluted (indirect). However, most indirect use happens without planning.

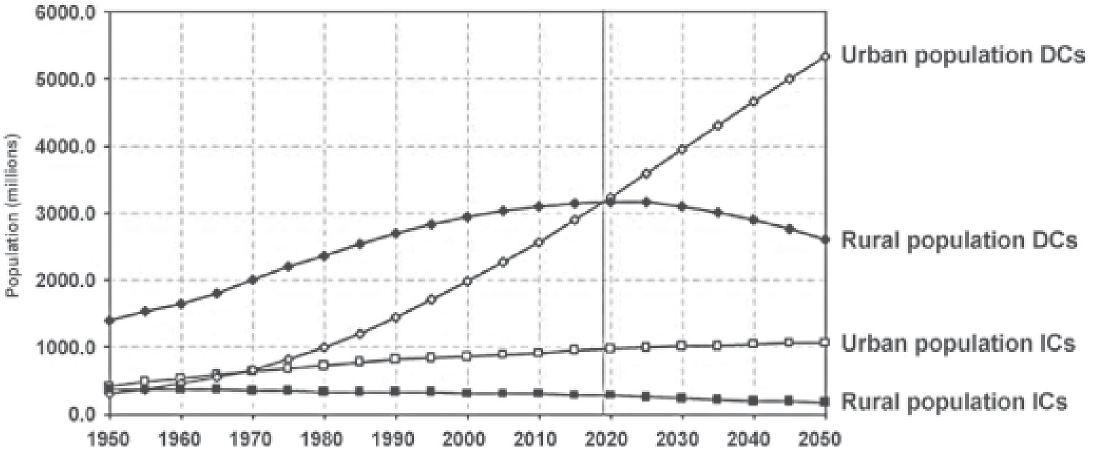
Source: Raschid Sally and Jayakody, 2008 and Jimenez and Asano, 2008

3.1.2 Factors driving wastewater use in irrigated agriculture

There are a variety of factors driving wastewater use in agriculture (physical, economic, social and political) but the main one is the lack of fresh water that, together with a high level of local water demand, leads to **water scarcity, stress and competition.** Wastewater is sometimes the only reliable available water source for agriculture as fresh water is allocated for industries and households. In arid and semi-arid regions freshwater availability is low by nature, but even in rainy regions pollution of water sources may reduce the amount of water that is safe to use. Population growth, especially in urban and peri-urban areas (Figure 16), is increasing pressure on water quality because of the growing amount of wastewater produced. Population growth is also increasing water demand both directly and indirectly through an increasing food and fibres demand. In addition, climate change is expected to lower water availability in certain areas and in certain periods. Together these factors are leading to an increasing use of wastewater in agriculture.

In developing countries direct use of untreated wastewater is also driven by **poverty**, which limits the 'coping capacity' of cities to respond to the infrastructure needs of urbanization, e.g. with comprehensive wastewater treatment. (Raschid.and Jayakody, 2008).

FIGURE 16: WORLD POPULATION FROM 1950, PROJECTED TO 2050 DCS = DEVELOPING COUNTRIES; ICS = INDUSTRIALIZED COUNTRIES



Source: United Nations (2008)

In industrialized countries and tourist areas **environmental protection and enhancement** in combination with **wastewater management needs** represent an emerging driver for direct use of reclaimed water. In areas with more stringent wastewater discharge standards, such as in Europe, United States, Australia and South Africa, water reclamation and reuse becomes a competitive alternative both from economic and environmental viewpoints.

3.1.3 Opportunities and risks

New source of fertilizers – Wastewater contains the macro and micro nutrients (e.g. nitrogen, phosphorus, potassium, calcium and magnesium) that plants need to grow. When safely used in agriculture it leads to eventual savings for fertilizer. In fact in some areas it may be the only affordable source of fertilizers for poor farmers. Therefore, the use of wastewater can be a reliable source of nutrients for urban and peri-urban agriculture, which can raise incomes, reduce poverty and improve food and nutritional security. Additionally, at the sight of the global phosphorus crisis, with a peak in global phosphate rock reserves foreseen by around 2030 (Cordell *et al* 2009), wastewater can become an alternative and relevant source of this essential nutrient.

Available all year round – Unlike rainwater or natural water courses, wastewater is a reliable source of water all year round, much less dependent on weather changes and climate variability. Urban and periurban farmers can benefit from a more reliable source of water which allows growing more crops per year resulting in increased yields and incomes for periurban farmers.

Low cost wastewater treatment – When wastewater treatment services are not provided, the use of wastewater for agriculture acts as a low-cost treatment method, taking advantage of the capacity of soil and plants to naturally remove contamination. Therefore, the use of wastewater for irrigation helps to reduce downstream health and environmental impacts that would otherwise result if wastewater was discharged directly into surface bodies.

Health risks - Wastewater often contains a variety of pollutants: salts, metals, metalloids, pathogens, residual drugs, organic compounds, endocrine disruptor compounds and active residues of personal care products. Any of these components can harm human health and the environment. (WHO/FAO/UNEP, 2006). Farmers can suffer harmful health effects from contact with wastewater, while consumers are at risk from eating vegetables and cereals irrigated with wastewater (typhoid, etc.).

Environmental risks - Wastewater use poses environmental risks, especially in relation to soil and groundwater pollution (salinization of soil, clogging, pollution of water resources, etc.). Generally, the use of domestic wastewater poses less risk to the environment than the use of industrial wastewater, especially where industries use or produce highly toxic chemicals. Industrial discharges containing toxic chemicals are mixed with domestic wastewater in many countries, creating serious environmental problems and, where the wastewater is used for crop irrigation, endangering the health of the farmers and product consumers. Efforts should be made to reduce or eliminate practices that entail the mixing of domestic and industrial wastewater, particularly where wastewater is used for agriculture.

The use of wastewater in agriculture may have both positive and negative impacts. With careful planning and management, the use of wastewater for agriculture can be beneficial to farmers, cities and the environment.

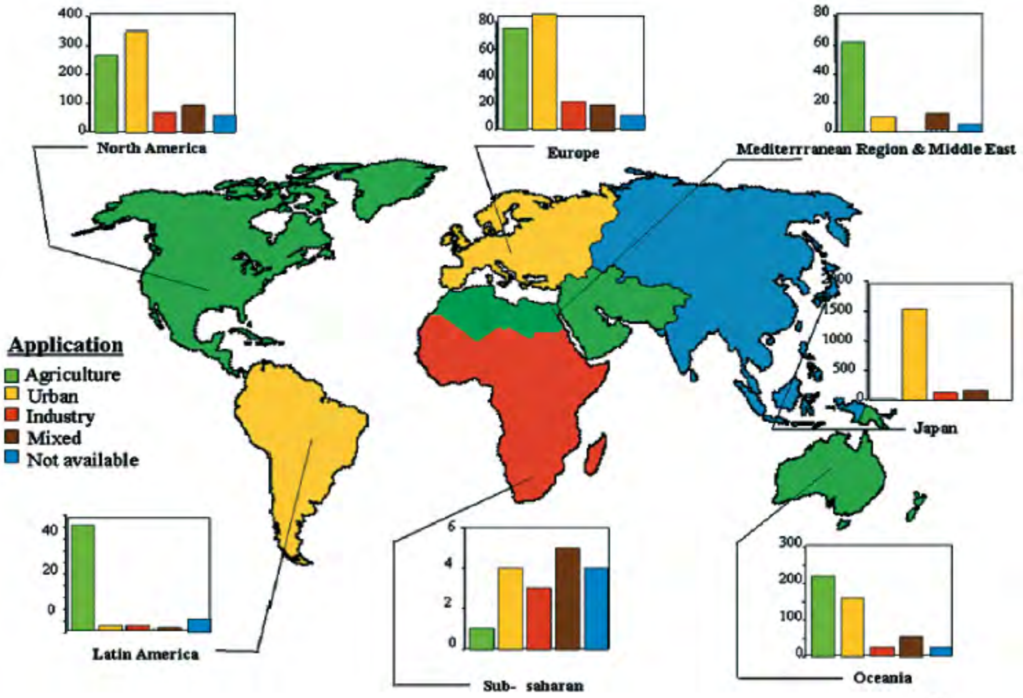
3.1.4 Regional overview

Planned versus unplanned reuse

Planned water reclamation and reuse is an already widespread strategy in developed regions and is expanding throughout the world. Figure 17 shows the results of a survey carried out during the European Commission project AQUAREC in 2003. The number of municipal water reuse schemes identified worldwide is sorted per type of reuse application. The types of application are split into five categories: 1) agricultural irrigation; 2) urban, recreational and environmental uses, including aquifer recharge; 3) processing water for industry; 4) (indirect) potable water production; and 5) combinations of the above (multipurpose).

Most of the 3 300 water reclamation facilities identified for planned water reuse are located in developed regions. For example over 1 800 were identified in Japan, over 800 in the United States, 450 in Australia and 230 in the European Union.

FIGURE 17: NUMBER OF IDENTIFIABLE PLANNED WATER REUSE SCHEMES IN SEVEN REGIONS OF THE WORLD PER TYPE OF REUSE APPLICATION



Source: European Commission, 2006

On the other hand, developing regions had fewer planned reclamation facilities: about 100 sites in North Africa and the Near East area, 50 in Latin America and 20 in sub-Saharan Africa. Those numbers are destined to become outdated quickly since many projects were identified in an advanced planning phase, and some countries such as China were not included in the survey.

Previous data do not include unplanned and indirect use of wastewater, which is a common practice in developing regions especially for agricultural purposes. This unplanned irrigation has been broadly reported in low-income countries in Africa, Latin America and Asia, but data on this regard is very scarce because of the unplanned nature of the wastewater use.

Developed and developing countries

Box 2 and Box 3 summarize the main characteristics of wastewater use for irrigation in both developing and developed regions. Information is presented on the main drivers behind wastewater use, type of guidelines followed and main approaches.

Agriculture represents an important demand on water and, as a consequence, is the biggest user of wastewater by volume among all the different uses of water. Overall, surface irrigated with untreated wastewater is substantially higher than that irrigated with treated wastewater. This is especially the case for developing and low-income countries (Jiménez and Asano, 2008).

BOX 2: OUTSTANDING CHARACTERISTICS IN DEVELOPING REGIONS

Near East and North Africa (low and middle income countries)

- The main driver of reuse is water scarcity
- Reuse performed with partially treated or untreated wastewater
- Agricultural irrigation is the main reuse activity
- WHO guidelines basically followed

Central and South Africa

- Little available information on reuse practices
- Water reuse is driven by water scarcity and a lack of sanitation
- Wastewater is appreciated as a reliable water resource and for its nutrient content
- Are starting to follow WHO guidelines but with problems

Central and South America

- Water reuse is driven by the interest in recycling nutrients contained in wastewater in poor soil areas, the lack of sanitation that make raw sewage available for irrigation, and water security in the Caribbean Islands, Mexico and Peru (water scarce countries).
- Wastewater is frequently used untreated and to irrigate crops directly or indirectly. Farmers appreciate this wastewater because it is a reliable water source, because of its nutrient content and because of its low or zero cost.
- Public policies tend to control unplanned reuse rather than promote planned use.
- Most of the countries follow WHO guidelines but have problems

Asia (middle and low income countries)

- Water reuse is driven by water scarcity, lack of sanitation and demand in high population density areas.
- Perform reuse for agriculture and aquaculture

Source: Adapted from Jimenez and Asano, 2008

BOX 3: OUTSTANDING CHARACTERISTICS IN DEVELOPED REGIONS

Europe

- Water is a scarce resource in Southern Europe (Mediterranean region) where agriculture is the main user of wastewater.
- Wastewater use in agriculture is driven by: a) water scarcity; and b) stringent effluent discharge regulations.
- European countries use either WHO Guidelines or California's Title 22 standards (see Box 4 and 5).

North America

- Reuse is only practiced in some states/provinces because of chronic and temporary water shortage, fast growing water demand in urbanized areas, stringent standards for wastewater discharge, the increased cost of mobilizing new water resources and environmental constraints.
- The first standards for water reuse in the world were established in the State of California in 1918. This legislation evolved into the Title 22 standards, which are stringent because of the high level of public health protection required by the State.
- 22 out of 50 States comprising the United States have water reuse standards. Some follow the style of Title 22 standards' but others do not
- In 2005 the United States Environmental Protection Agency released new water reuse criteria

Oceania

- Water reuse is driven by regional water scarcity and stringent effluent discharge conditions to protect ocean, coastal and surface water ecosystems.
- Australia is undertaking important water reuse programmes. It has developed a new water policy based on mandatory measures and incentives for promoting water reuse.
- Currently, reuse is increasing at a rate of 10-17 percent per year.
- Of reclaimed water used, 28 percent is for agricultural irrigation.
- Water reuse schemes have been developed with subsidies, where the recycled water cost has been set at 30 percent of the cost of potable water.

Near East and North Africa (high income countries)

- The main driver for reuse is water scarcity.
- There are water reuse schemes for agricultural and landscape irrigation.
- Use reclaimed water where there is a high demand for water (see Box 2).
- Wastewater use standards are inspired by the California Title 22.

Asia (high income countries)

- Water reuse is driven by water scarcity, demand in high population density areas, and in one case (Singapore) by international political pressure on water resources.
- Performing reuse for municipal and industrial purposes (like Japan and Korea)
- Municipal reuse is for activities requiring low quality water (like toilet flushing) but also for human consumption (only Korea)

Source: Adapted from Jimenez and Asano, 2008

BOX 4: CALIFORNIAN TITLE 22 REGULATION (STATE OF CALIFORNIA, 2000)

- Attempts to achieve near zero-risk, with relatively expensive compliance requirements.
- It is flexible: 43 uses, four treatment levels and alternative treatment is possible.
- Primarily developed in response to projects to eliminate public health risks.
- Criticized for not being a risk-based regulation and for being overly conservative.
- This approach may be applicable to countries with a strong domestic financial market like Israel, the European Union and Australia, but when a critical level of financing is not available this model cannot be considered to be of practical use.

Source: European Commission, 2006

BOX 5: WHO/FAO/UNEP GUIDELINES (WHO, 2006)

- Designed to facilitate reuse, recognizing that regulations should be realistic and able to be realized within the context they are to be applied.
- Standards criticized for being too low.
- This approach is valuable to countries with limited financial means and wastewater treatment infrastructure. In economies in transition, too strict standards would virtually ban the reuse practice but this does not necessarily stop the reuse of often even less treated or untreated wastewater.

Source: European Commission, 2006

Many high-income and water-scarce countries, especially in the Near East and the Mediterranean region, are intensively using treated wastewater for irrigation. In a number of these countries – Israel, Jordan, and Tunisia – water reuse provides the greatest share of irrigation water. Israel is the world's leader in this area, with over 70 percent of collected and treated wastewater re-used for agricultural purposes (Kanarek and Michail, 1996).

3.1.5 Common patterns

Even when use of wastewater in irrigation can be driven by many factors and the resulting schemes for wastewater use can be very heterogeneous, common patterns can be detected in different countries.

- Lack of quality water and poverty drive untreated wastewater use in urban and peri-urban agriculture.

This is a common pattern in sub-Saharan Africa and other poor regions where there is no economic capacity to afford conventional sanitation and wastewater treatment facilities. This poses health, environmental and agriculture risks if no additional measures are applied.

- Water scarcity and health and environment protection drive reclaimed wastewater use in high-income countries:

This is a common pattern in countries such as Israel, Spain, Australia or the United States (California and Florida) where highly effective sanitation and treatment technology is used in planned reclamation facilities. This is a costly approach but reduces risk almost to zero.

- Water scarcity drives treated wastewater use in emerging (middle income) countries.

This is a common pattern in areas were low cost technologies are applied providing partially treated wastewater for irrigation purposes. This approach poses moderate risks to health, environment and agriculture yield.

Different patterns and schemes for wastewater use for irrigation will require a specific approach to minimize the associated risks and maximize the potential benefits.

3.1.6 Policy and institutional framework

To maximize benefits and minimize risks related to the use of wastewater for irrigation a robust policy and institutional framework needs to be designed. In many countries, where wastewater use in agriculture takes place, these frameworks are lacking.

Policies for wastewater use can be implemented through several types of instruments: laws and regulations, economic measures, information and education programmes all focusing on treatment or non-treatment options depending on the local socio-economic conditions (Table 4).

The institutional framework on wastewater use in irrigation is especially complex since there may be a great number of institutions involved in dealing with: i) health protection; ii) agriculture; and iii) water management at different administrative levels: international, national, local. Responsibilities and the jurisdictions of the public institutions need to be clear and coordination mechanisms should be created to establish comprehensive and effective policies.

Policies on the use of wastewater for irrigation can have one or more objectives (conserve water and nutrients, maximize agricultural yields, protect public health, prevent environmental damage, meet produce quality standards for domestic and international trade...). Defining these objectives is important for developing a national policy framework. The right policies can facilitate the safe use of wastewater for agriculture.

An essential issue is to know the current institutional framework well and to identify and clarify the role (responsibilities and jurisdictions) of the different institutions (ministries, agencies…) at both national and local level.

3.1.7 Management strategies to reduce risks

Advanced treatment of wastewater before use is to eliminate health and environmental risks. This is the main approach used when planning wastewater reuse facilities in developed countries. In many developing countries, however, the cost of construction, operation and maintenance, and the lack of required skills, are the primary constraints to wastewater treatment capacity. In this situation it may be wiser to manage or minimize risk, rather than attempting to eliminate it through advanced wastewater treatment.

Minimizing health risks:

In most developing countries wastewater treatment is a long-term strategy. Interim solutions may be needed to protect farmers and public health (CA., 2007). In these countries, the focus has been on prioritizing afford-

TABLE 4: INSTRUMENTS TO IMPLEMENT POLICIES ON WASTEWATER USE IN IRRIGATION

	Laws and regulations	Plans and programmes	Economic framework	Education, social awareness and social marketing
Focus on treatment options	Especially middle to high income countries where promotion of planned use of treated wastewater is needed			
Focus on non-treatment options	Especially in low to middle income countries were controll of unplanned wastewater use is needed			

able and easily adoptable risk-management strategies. Adopting the multiple-barrier approach can reduce human and crop exposure to toxic compounds and pathogens. The 2006 WHO-FAO-UNEP 'Guidelines on the safe use of wastewater in agriculture', present a number of risk management strategies that can be implemented (Figure 18).

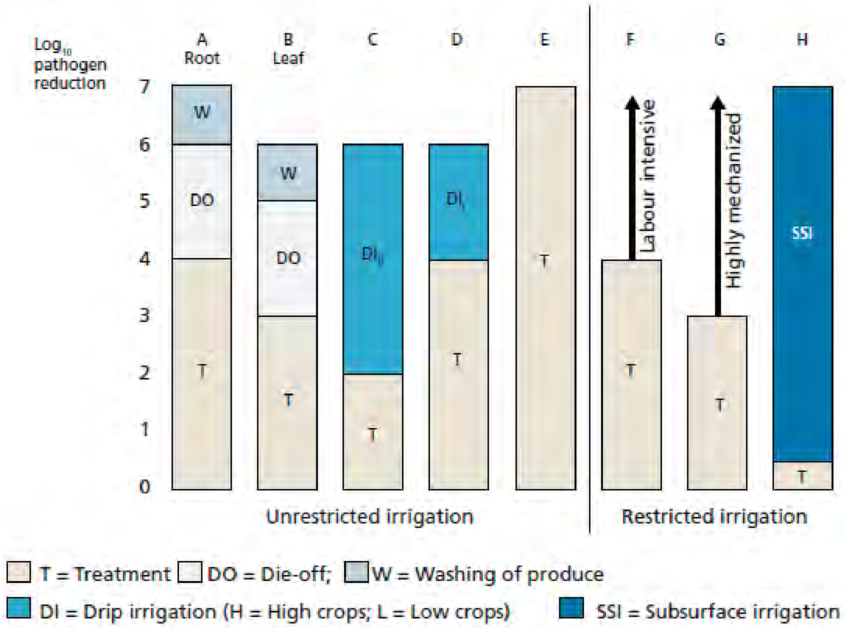
Though unpopular, *protective measures* such as wearing boots and gloves can reduce farmers' exposure. Farmers can wash their arms and legs after immersion in wastewater to prevent the spread of infection. Improvements in *irrigation methods* and in *personal and domestic hygiene* can be encouraged by public awareness campaigns. Drip irrigation can protect farmers and consumers by minimizing crop and human exposure, but pretreatment of wastewater is needed to avoid clogging of emitters. A combination of *farm-level and post-harvest* measures can be used to protect consumers, such as restricting crops to be used (industrial or inedible crops) or products that require cooking before consumption. Farmers can stop applying wastewater long before harvest, to reduce potential harm to consumers. Vegetables can be washed before sale or consumption and storage methods can be improved. Public agencies can implement child immunization campaigns against diseases that can be transmitted by wastewater use and target selected populations for periodic antihelminthic campaigns.

In many developing countries, where high-tech wastewater treatment is not feasible, treatment can be phased in by first introducing primary treatment facilities, particularly where wastewater is used directly for irrigation. Secondary treatment can be implemented in some areas by using low-cost options, such as waste-stabilization ponds, constructed wetlands and up-flow anaerobic sludge blanket reactors (Mara 2003).

Minimizing environmental risks:

Nutrients in municipal wastewater can contribute to crop growth, but periodic monitoring is needed to avoid imbalanced nutrient supply. *Periodic monitoring* is required to estimate the nutrient loads in wastewater and to adjust fertilizer applications.

FIGURE 18: OPTIONS TO REDUCE PATHOGENS ALONG THE FOOD CHAIN WITH DIFFERENT COMBINATION OF HEALTH PROTECTION MEASURES THAT ACHIEVE THE HEALTH-BASED TARGET OF ($\leq 10^{-6}$ DALYS) PER PERSON PER YEAR.



Source: WHO/FAO/UNEP 2006

Salt levels in wastewater, even after most treatments, are often too high for unrestricted irrigation. To maintain a favourable salt balance, excess water must be able to drain from the root zone. *Good drainage* is particularly important in arid and semi-arid areas. The quality of drainage water should be controlled and must be disposed of properly.

3.1.8 Management strategies to maximize benefits

To maximize farmers' benefits several technical and market issues should be addressed:

- Selection of crops, agricultural practices and technologies:
  Raw, but also treated, wastewater has certain characteristics that might affect crop productivity and, consequently, farmers' income. For example wastewater, even after secondary treatment, typically has high salt concentration and therefore actions to prevent soil salinity and harmful effects on crops must be undertaken (see the Sections on *Actions to prevent water salinization from agriculture* and *Improving management of saline and sodic water*). Suspended solids in wastewater is another example of a constraint that needs to be managed. Suspended solids in wastewater may increase clogging of soil and of some types of drip-irrigation systems. To prevent this, the right irrigation technology and the right agricultural practice should be implemented. Especially relevant is the selection of crops and varieties that are resistant to low-quality water and salinity.
- Management of nutrients to meet crop requirements in different seasons:
  Often there is no control of the total amount of nutrients used for crop production. Farmers should periodically measure nutrient concentrations in applied wastewater or, at least should have an indication of the average nutrient content in the water being used. When farmers do not have the resources or capacity to implement this measurement they will need public support. When nutrient content in wastewater is known, farmers can better match crop requirements and the amount of nutrients applied by diluting wastewater or by adding extra fertilizer if feasible.
- Approach to market and consumers:
  Consumers are often reluctant to buy products that have been irrigated with wastewater, even when treated. Many countries using reused water for irrigation face exportation restrictions and their products have no access to more profitable markets. This is often because of a lack of confidence and cultural and religious barriers. Strengthening consumer confidence, and dismantling unjustified cultural and religious barriers, should be a priority. Certifying that crops were produced in a safe environment, with a special focus on the safe use of wastewater, would increase produce safety and the confidence of both consumers' and markets'. More information on how to create certification programmes is shown in FAO, 1997.

Farmers should be provided with specific guidelines on dealing with the above-mentioned issues and to support production and access to markets. In addition, proper dissemination and education campaigns need to be designed to facilitate the adoption of such guidelines by farmers.

3.1.9 Planning and implementation

National plans and programmes should be developed with the participation of the stakeholders involved: public agencies and ministries, farmers, service providers, NGOs, researchers and universities. This participation should include communication strategies and data collection from stakeholders to ensure their interests are covered.

Key factors such us religion, economic financial considerations, public perception, cultural barriers, psychological taboos, technical feasibility and institutional capacity needs to be considered to successfully implement wastewater use schemes.

3.1.10 Economic and financial considerations

Projects related to wastewater use for irrigation should be economically justified and financially feasible, otherwise they may fail over the long term.

The economic appraisal of a project should be from the viewpoint of the regional basin, comparing its economic costs and benefits. Although farmers may be net beneficiaries when using treated wastewater, compared with their previous and alternative sources of water, this depends very much on local circumstances and the scale of farming (smallholder farmers or large-scale commercial farming). In any event their net benefits are unlikely to offset the full cost of the scheme. On the other hand, the benefits to urban and industrial users could be sizeable and, in most cases, would be the principal justification for the project. The net impact of the project on the local and downstream environment will also be site specific, and there are likely to be both benefits and costs (FAO, 2010).

Once the basic economic justification for the project is established, the next step is to examine its financial feasibility. The distribution of the costs and benefits of the project among the different stakeholders is crucial to its feasibility. Its impact on the finances of the various stakeholders – national government, regional water authority, farmers, municipal utility and/or other major players should be assessed. Financial gainers and payers should be identified to gauge the incentives, or conversely the penalties, to be applied and the type of funding that would be appropriate. Water charges, taxes, subsidies, soft loans, environmental service payments, and other instruments could all form part of the financing proposals.

3.2 Saline, sodic and desalinated water use in agriculture

3.2.1 Problem statement

Surface runoff and subsurface drainage from agriculture systems often have higher salt content than the originally used irrigation water. This is because of excessive use of mineral fertilizers, inappropriate irrigation methods, irrigation of saline soils and leaching fractions applied. In addition, use of water resources that are considered saline or sodic is increasing worldwide as shown in Section 1.1. Salinized drainage water and groundwater are often used for irrigation purposes posing agriculture and environmental risks owing to soil salinization and water quality degradation downstream. Problems from soil salinization and sodicity are described in Section 1.1.

Desalination of salty groundwater and brackish drainage water is an available option for coping with the problem of water salinization. In addition, when seawater is desalinated, it is used to augment freshwater resources (FAO, 2006). Even if this technology is interesting the main constraint is the massive use of energy required and the associated costs.

3.2.2 Global overview

Use of saline and sodic water

Currently no overall and complete global or regional quantifications exist for saline and sodic drainage use for agriculture. Nevertheless, Figure 1 gives an idea of the extent of this practice.

The cases of Egypt and India illustrate the importance of the issue. Egypt uses approximately 5 billion m^3 of drainage water for irrigation in the Nile Delta, where drainage water and freshwater are mixed. In India, approximately 32 billion m^3 of saline and sodic groundwater are withdrawn annually for different uses, mainly for agriculture. The use of saline or sodic waters is a common practice in many other countries such as

Bangladesh, China, Iran, Pakistan, Syria, Spain or the United States, especially to irrigate salt-tolerant plants and trees, but also conventional grains and forage (CA, 2007).

Use of desalinated water in irrigation

Global desalination capacity has grown rapidly worldwide in the last 30 years (Figure 19). Figure 20 presents the share of the installed desalination capacity in terms of the process used. The multistage flash distillation process makes up the highest total production capacity of desalinated waters, followed closely by Reverse Osmosis (RO). Other processes are comparatively smaller in production capacity. Although thermal distillation plants make up about 21 percent of the world total of desalinating facilities, they produce more than half of the total desalinated waters because they are larger than RO facilities. RO is particularly appealing because recent advances in membrane technology allow for modular construction of desalinating facilities to meet small- to large-volume desalination needs (FAO, 2006). From an inventory by Wangnick (2000), seawater and brackish water make up about 59 percent and 41 percent, respectively, of the total water sources for desalination.

RO is the preferred desalination technology for agriculture uses because of the cost reductions driven by improvements in membranes in recent years.

Spain provides an important example of the application of desalinated water for irrigation. Spain has more than 300 treatment plants (about 40 percent of the total number of existing plants worldwide) and 22.4 percent of the total desalinated water is used for agriculture. Most of these plants process brackish water (only 10 percent of the total desalinated water for agriculture originates from seawater) and are located in coastal areas or within 60 km of the sea (FAO, 2003). In this country, small and medium-sized brackish-water desalination plants, with a capacity of less than 1 000 m^3/d (11.6 litres/s), are common because they adapt better to the requirements of individual farmers and to the existing hydraulic structures.

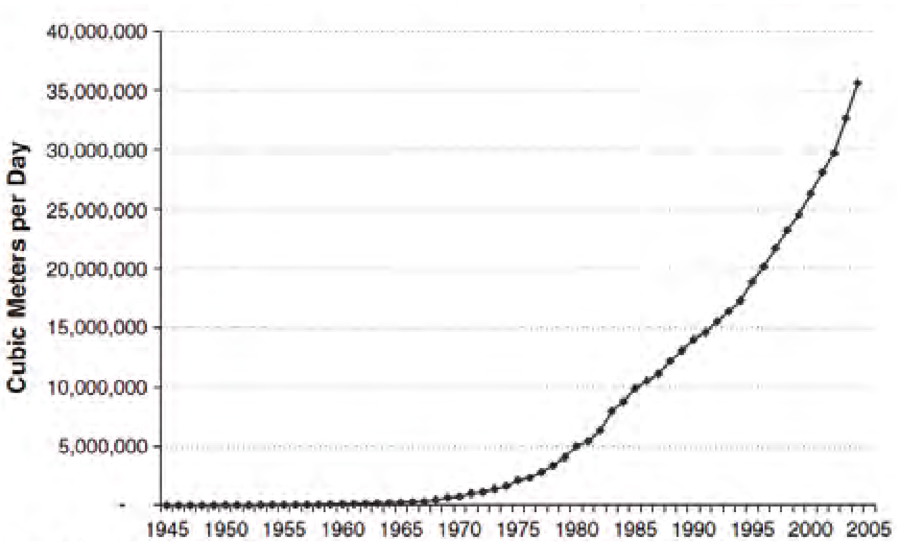
3.2.3 Improving management of saline and sodic water

When dealing with salinity it is important to bear in mind that many land and irrigation areas have varying levels of tolerance to increases in salinity. Therefore, salinity must be considered in the context of the particular asset at risk and the value of that asset. A salinity risk assessment should be carried out to determine the intensity of the actions to apply and the methods to follow. In areas identified as having a high hazard level a good salinity monitoring programme should be developed. In addition, actions to prevent farther salinization of land and water or to remedy saline or sodic soils need to be implemented.

The prevention of salinity, sodicity and waterlogging requires more efficient irrigated agriculture or effective drainage measures, or better still a combination of the two. Improved efficiency of water use has been the subject of much research by irrigation engineers and agronomists, and many techniques are now employed, of varying technical complexity and cost. An extensive description of these techniques is given by Ghassemi, *et al.*, 1995 with a detailed review of engineering options, biological options, policy options and a wide range of tools that can be used to manage and monitor salinization.

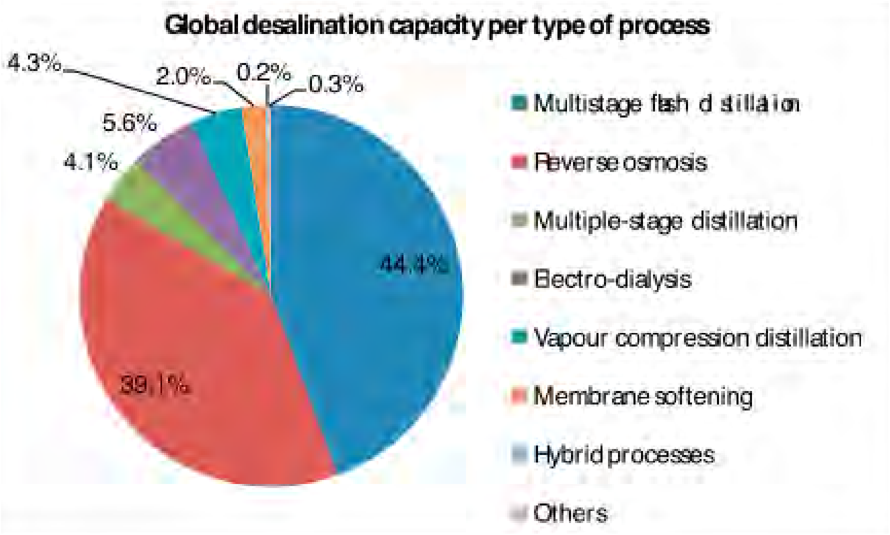
Drainage is the primary method of controlling soil salinity. A drainage system should permit a small fraction of the irrigation water (about 10 to 20 percent, the drainage or leaching fraction) to be drained and discharged out of the irrigation project. This can be achieved by open ditches, tile drains or pumping from boreholes. The choice depends on the permeability of the soil, subsoil and underlying aquifer material, on the funds available for the capital works, on the resources of local communities for operation and maintenance and the energy costs of pumping.

FIGURE 19: **CUMULATIVE TOTAL CAPACITY OF DESALINATION PLANTS IN THE WORLD. 1945 TO 2004**



Source: Wangnick/GWI, 2005

FIGURE 20: **GLOBAL DESALINATION CAPACITY PER TYPE OF PROCESS**

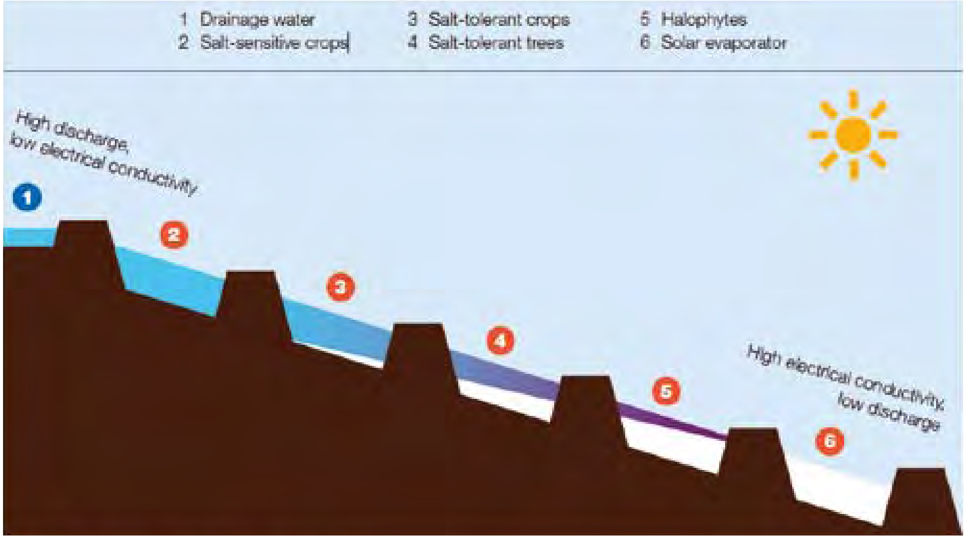


Source: Wangnick/GWI, 2000

Crop selection is another crucial issue related to salinity or sodicity management in agriculture. Crops vary considerably in their ability to tolerate saline conditions, for example durum wheat, triticale or barley tolerate higher salinity than rice or corn. Irrigation with saline water can even improve the quality of some vegetables, as the sugar content in tomatoes or melons can increase.

Saline drainage water can be reused downstream directly of blended with freshwater. These approaches would require planning at the watershed scale to adapt agriculture practices and crops to the increasing salt content after different cycles of reuse (Figure 21).

FIGURE 21: SEQUENTIAL REUSE OF DRAINAGE WATER



Source: CA, 2007

Reuse of saline water can require treatment before use. Desalination of salty groundwater, brackish drainage or even seawater is an option of increasing importance. In the past, the high cost of desalinating and the energy required have been major constraints to large-scale production of freshwater from brackish waters and seawater. However, desalinated water is becoming more competitive for urban uses because desalinating costs are declining (Table 5) and the costs of surface water and groundwater are increasing. In spite of this development, the costs of desalinated water are still too high for the full use of this resource for irrigated agriculture, except for intensive horticulture for high-value cash crops, such as vegetables and flowers (mainly in greenhouses) grown in coastal areas (where safe disposal is easier than in inland areas).

The discharge of salty drainage water may pose environmental problems to downstream areas. The environmental hazards should be considered carefully and, if necessary, mitigating measures taken (FAO, 2007b). If possible, drainage should be limited to wet seasons only, when the salty effluent inflicts the least harm. Constructed wetlands are a relatively low-cost option for protecting aquatic ecosystems and fisheries, either downstream of irrigated areas or in closed basins. The volume of drainage water requiring disposal can be reduced by treatment and cyclic reuse. Disposal options include direct discharge into rivers, streams, lakes, deserts, and oceans and discharge into evaporation basins.

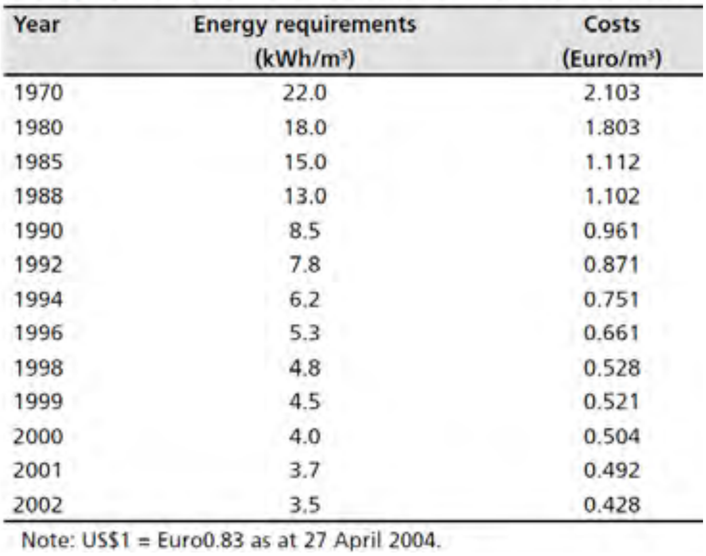
3.3 Arsenic-laden water use in agriculture

3.3.1 Problem statement

Natural arsenic in groundwater at concentrations above the WHO drinking water standard of 10 µg/litre is not uncommon, and the realization that water resources can contain insidious toxic concentrations of naturally-occurring chemical constituents, such as arsenic, is fairly recent and increasingly urgent.

Sources of arsenic that have been created by people such as mineral extraction and processing wastes, poultry and swine feed additives, pesticides and highly soluble arsenic trioxide stockpiles are also not uncommon and have caused further contamination of soil and groundwater.

TABLE 5: ENERGY CONSUMPTION AND SEAWATER DESALINATION COSTS IN SPAIN



Year	Energy requirements (kWh/m³)	Costs (Euro/m³)
1970	22.0	2.103
1980	18.0	1.803
1985	15.0	1.112
1988	13.0	1.102
1990	8.5	0.961
1992	7.8	0.871
1994	6.2	0.751
1996	5.3	0.661
1998	4.8	0.528
1999	4.5	0.521
2000	4.0	0.504
2001	3.7	0.492
2002	3.5	0.428

Note: US$1 = Euro0.83 as at 27 April 2004.

Source: FAO 2003

The use of arsenic-polluted groundwater has increased considerably in the last decades, especially in Asia. In this period arsenic pollution of these water resources was unnoticed. The aim was to provide farmers with inexpensive sources of drinking and irrigation water. Thus, millions of shallow tube wells were constructed to withdraw groundwater. This had very positive effects providing farmers with water during the dry season and during periods of drought and offered an inexpensive source of drinking-water mostly free of waterborne diseases. It released, however, an enormous amount of arsenic that increased human exposure to this pollutant and posed significant health risks.

Estimates of arsenic toxicity (arsenosis) from drinking water, causing skin lesions and various types of cancers, indicate about 130 million people are impacted (Nordstrom, 2002).

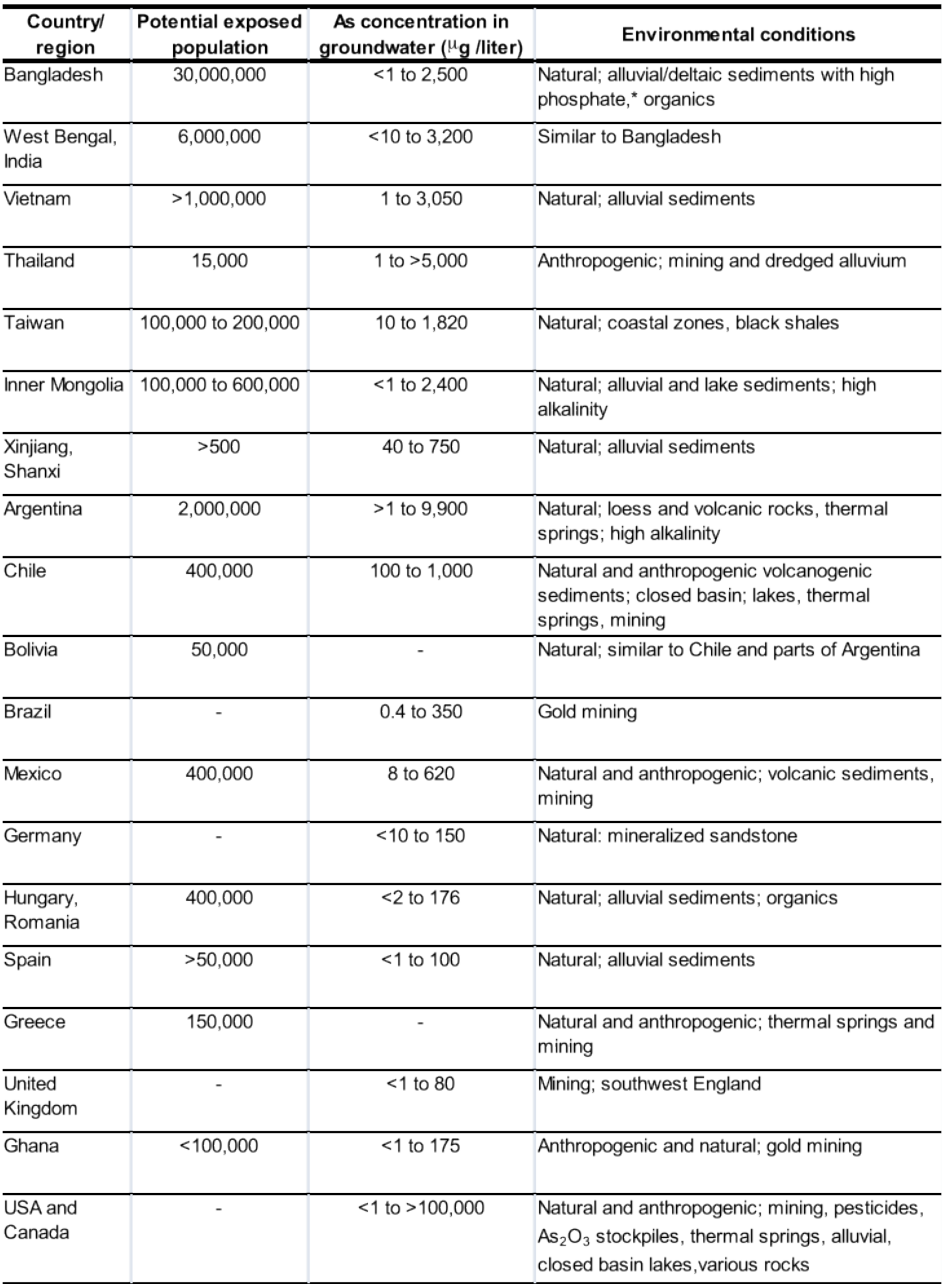
Besides drinking water health risks, there is a concern about the potential levels of arsenic entering the food chain through absorption by crops from irrigated water. Widespread use of As-contaminated irrigation water ultimately leads to issues of food security, food safety and degradation of the environment through:

1. Reduced agricultural productivity resulting from As toxicity to crops (e.g. rice) and possibly to animals when high As crops (e.g. rice straw) are used for feed.
2. Constraints on land use because of arsenic build up in soils, toxicity to crops and/or unacceptable quality of agricultural products.
3. Creation of spatial variability in soil As, Fe and P levels that make agricultural management of land difficult.
4. Enhanced exposure of humans to As through agricultural products containing elevated levels of As, especially rice, and through food system and environmental pathways of arsenic, e.g. high As animal products, dermal absorption while weeding rice paddies, use of high As straw and manure as fuel.

3.3.2 Extent of the problem

Arsenic contamination in groundwater has been reported in more than twenty countries around the world (Nordstrom, 2002) and, in many, shallow groundwater is used for both drinking and irrigation, potentially exposing millions of people (Table 6).

TABLE 6: **GLOBAL ARSENIC CONTAMINATION IN GROUNDWATER (NORDSTROM 2002)**



Country/ region	Potential exposed population	As concentration in groundwater (µg /liter)	Environmental conditions
Bangladesh	30,000,000	<1 to 2,500	Natural; alluvial/deltaic sediments with high phosphate,* organics
West Bengal, India	6,000,000	<10 to 3,200	Similar to Bangladesh
Vietnam	>1,000,000	1 to 3,050	Natural; alluvial sediments
Thailand	15,000	1 to >5,000	Anthropogenic; mining and dredged alluvium
Taiwan	100,000 to 200,000	10 to 1,820	Natural; coastal zones, black shales
Inner Mongolia	100,000 to 600,000	<1 to 2,400	Natural; alluvial and lake sediments; high alkalinity
Xinjiang, Shanxi	>500	40 to 750	Natural; alluvial sediments
Argentina	2,000,000	>1 to 9,900	Natural; loess and volcanic rocks, thermal springs; high alkalinity
Chile	400,000	100 to 1,000	Natural and anthropogenic volcanogenic sediments; closed basin; lakes, thermal springs, mining
Bolivia	50,000	-	Natural; similar to Chile and parts of Argentina
Brazil	-	0.4 to 350	Gold mining
Mexico	400,000	8 to 620	Natural and anthropogenic; volcanic sediments, mining
Germany	-	<10 to 150	Natural: mineralized sandstone
Hungary, Romania	400,000	<2 to 176	Natural; alluvial sediments; organics
Spain	>50,000	<1 to 100	Natural; alluvial sediments
Greece	150,000	-	Natural and anthropogenic; thermal springs and mining
United Kingdom	-	<1 to 80	Mining; southwest England
Ghana	<100,000	<1 to 175	Anthropogenic and natural; gold mining
USA and Canada	-	<1 to >100,000	Natural and anthropogenic; mining, pesticides, As_2O_3 stockpiles, thermal springs, alluvial, closed basin lakes,various rocks

Source: Nordstrom 2002

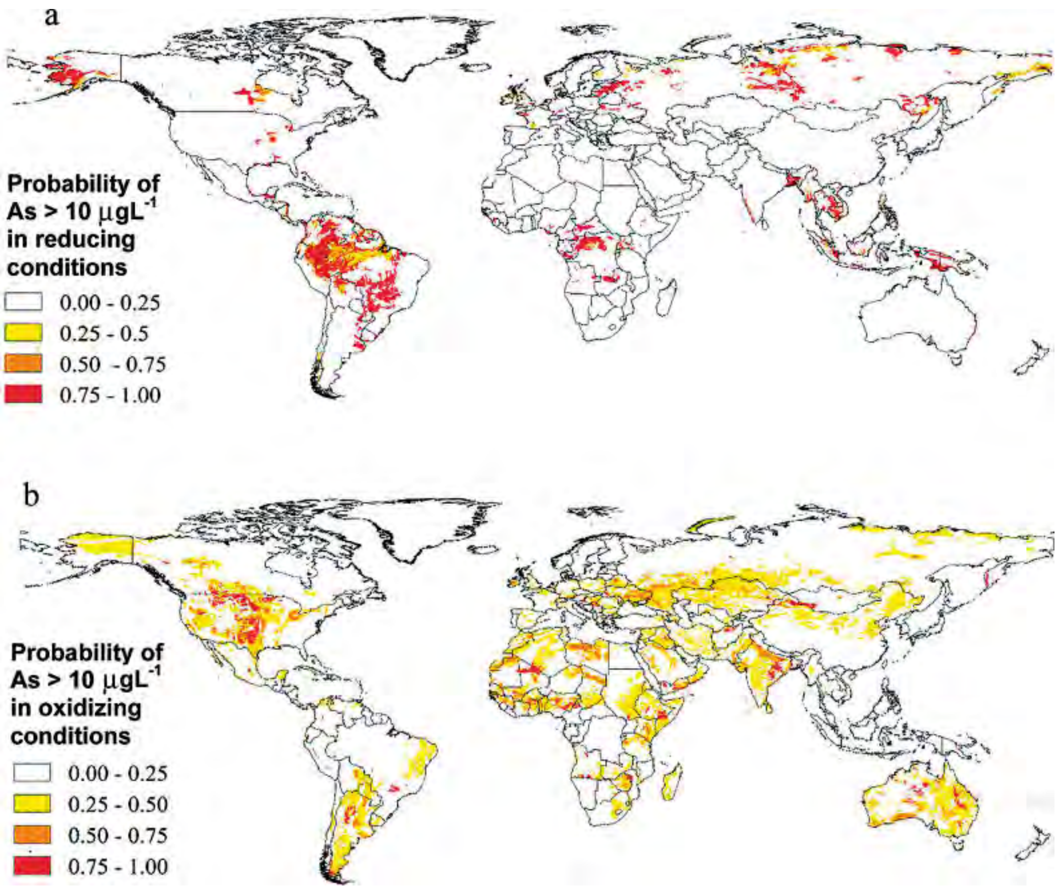
Although the main geochemical mechanisms of arsenic mobilization are well understood, and important cases have been reported around the world (Table 6) the real worldwide scale of affected regions is still unknown.

Amini *et al.*, (2008) conducted a study using a large database of measured arsenic concentrations in groundwater (around 20 000 data points) from around the world as well as digital maps of physical characteristics such as soil, geology, climate, and elevation to model probability maps of global arsenic contamination. (Figure 22). The probability maps based on modelling the above information correspond with the known contaminated regions around the world and delineate new untested areas that have a high probability of arsenic contamination. Notable among these regions are Southeast and Northwest China, central Australia, New Zealand, northern Afghanistan, and northern Mali and Zambia.

3.3.3 Knowledge gaps and remedial actions

Considerable effort has been made to study and develop practical and acceptable water treatment systems for rural households but remedial actions to reduce exposure to As through the food chain is less understood and controlled. This is an emerging issue and important knowledge gaps need to be filled (Box 6).

FIGURE 22: MODELED GLOBAL PROBABILITY OF GEOGENIC ARSENIC CONTAMINATION IN GROUNDWATER FOR (A) REDUCING GROUNDWATER CONDITIONS, AND (B) HIGH-pH/OXIDIZING CONDITIONS WHERE ARSENIC IS SOLUBLE IN ITS OXIDIZED STATE.



Source: Amini. et al., 2008

BOX 6: IDENTIFIED As KNOWLEDGE GAPS FOR ASIA

- The extent of using As-contaminated groundwater resources for irrigation in Asia has not been quantified.
- The scale of As accumulation in topsoils from As-contaminated irrigation water in Asia is unknown.
- The scale of land degradation caused by irrigation with As-contaminated water is unknown.
- Factors determining As accumulation in soils are not sufficiently understood and quantified.
- The relationship between As in water, soil and plants has not been quantified.
- Few management options have been developed to prevent and mitigate As-contamination of agricultural land.
- Uptake and toxicity of As in crops currently cannot be predicted.
- Limited knowledge is available about the differences between plant species and cultivars in As uptake, sensitivity, translocation and speciation.
- There is no plant toxicity data representative of the field situation.
- There is no insight into the risks of As in water and fodder for livestock and their food products.
- There are no policies concerning the use of As-contaminated groundwater for irrigation.
- Only limited data on inorganic As in rice, vegetables and other foods are available.
- The uptake efficiency/bio-availability of As in rice and other foods after consumption is largely unknown.
- The provisional tolerable daily intake for dietary inorganic As intake is still provisional 18 years after issuance, indicating uncertainties about the acceptable level.
- Globally, except for China, no food safety standards for inorganic As in foods have been found.
- A reliable and representative human health risk assessment for As in foods cannot be made at this stage.
- Data from countries other than Bangladesh for (inorganic) As in irrigation water, soil, crops and foods are very limited.
- Data on As in livestock and freshwater fisheries are so far insufficient to make any statement on the risks of As to animal health and the safety of food products from these sectors.

Source: Heikens, 2006

Most importantly, the scale of the problem needs to be better quantified. This should be based on scientifically justified methodologies resulting in reliable results, conclusions and recommendations. Close involvement of stakeholders from different sectors is necessary to optimize integrated and cross-sectoral programme coordination and implementation, which should include data sharing, human resources, funding and optimize the dissemination and integration of the outcomes in strategic planning and programming, thus ensuring sustainability.

Finally, it is worth mentioning that management options are being developed and successfully tested to prevent and mitigate As-contamination of agricultural land. For example, strategies to manage arsenic would enable rice production in Bangladesh to continue, which is so far the most arsenic exposed country (FAO, 2007c). Other strategies include:

1. Growing rice in an aerobic environment where As is adsorbed on oxidized Fe surfaces and is largely unavailable to rice.
2. Switching from As-contaminated shallow groundwater to uncontaminated surface or deep groundwater to avoid further build up of soil As. Unfortunately, the surface water option is limited and generally requires large irrigation development projects.
3. Identification or development of arsenic tolerant rice varieties, where arsenic uptake is also low.

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