CHAPTER 13

Water quality and nonpoint pollution: Comparative global analysis

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ABSTRACT: The improvement of the management of water resources quantity and quality in countries around the world requires better information and biophysical knowledge, both on water resources and on their associated ecosystems. The lack of basic information and knowledge makes very difficult the whole process of designing, implementing and enforcing water policies, and additionally promotes detrimental strategic behavior by stakeholders, regions and economic sectors. Sound water policies entail also the cooperation of stakeholders leading to collective action, because of the public good dimension of water. Therefore, besides information and knowledge, another essential feature is the right institutional setting. One component of this institutional setting is to have strong basin authorities, and the other component equally important is the involvement of stakeholders in basin authorities, so that all decisions are taken by them. Economic instruments advanced by some policy makers and water experts, can not substitute for collective action based on strong water institutions. Without the attainment of collective action, water policies are quite likely to fail.

Keywords: water quality, nonpoint pollution, economic instruments, cooperation, collective action

1 INTRODUCTION

The pressure on water resources has been mounting worldwide during the last century, creating problems in basins of rich and poor countries alike linked to the ever-increasing growth in population and economic activities at global scale. This pressure on water and the resulting damages have built up rapidly during last decades. The current situation is that water degradation is pervasive in many basins around the world, driven by the impacts of the escalating anthropogenic effects of human activities.

The problems created by these growing demands on water resources are twofold: one is water scarcity in watersheds brought about by excessive surface and groundwater withdrawals. The other is water degradation from pollution loads leading to many tracts of rivers and whole aquifers being spoiled, and losing their capacity to sustain ecosystem functioning and human activities.

The total amount of precipitations is 110,000 km^3, of which 40,000 km^3 are runoff and aquifer recharge or blue water, and 70,000 km^3 are soil storage or green water returning to the atmosphere through evapotranspiration. Anthropogenic water extractions have climbed from 600 km^3 to 3,600 km^3 between 1900 and 2000, along with the growth of population from 1,700 to 6,000 million. Of these extractions, 2,300 km^3 are employed for irrigation, 900 for industrial use and 400 for urban use (FAO-IFAD, 2006). Although water returns to basins from these human activities amount to 2,500 km^3, these returns contain large pollution loads that degrade heavily water receiving media.

In last decades, water scarcity has become widespread in most arid and semiarid regions around the world. There is a severe scarcity problem in almost all the important rivers in these regions, such as in the Nile, Ganges, Indus, Yellow, Yangtze, Tigris, Euphrates, Amu and Syr Daria, Murray-Darling, Colorado and Rio Grande. Surface and subsurface resources in these river basins are being depleted and their quality degraded. The scarcity problems in basins of arid and semiarid regions were created at first by extractions of surface waters, but at present they are compounded by the huge development of groundwater by individual wells during last decades, brought about by the adoption of pumping technologies with falling costs worldwide.

The largest groundwater extractions by country take place in India, USA and China with extractions above 100 km^3, and in Bangladesh, Pakistan and Iran with extractions above 50 km^3 (Björklund *et al.*, 2009; Vrba & van der Gun, 2004). All these countries have large aquifer systems being depleted located in the Indus basin, the Ganges basin, the Northern China plain, and the North America high plains. The region of the Indus, Ganges and Brahmaputra basins is the larger irrigated area in the world, extending 2.7 million hectare (Mha) over northern India, Pakistan, Bangladesh, Nepal and eastern Afghanistan. Large-scale estimates of irrigation acreage are available from Siebert *et al.* (2007). Irrigated acreage covers 1.2 Mha in the Indus basin and 1.1 Mha in the Ganges basin, and the mean flow per year of the Indus is 175 km^3 and that of Ganges is 400 km^3. Groundwater overdraft in this region has been estimated at 50 km^3/yr from satellite data (Tiwari *et al.*, 2009), with overdraft estimates by basin close to 35 km^3 in the Ganges-Brahmaputra and 10 km^3 in the Indus basin. In the India part of these basins, groundwater extractions per year are estimated at 280 km^3 with an overdraft amounting to 30 km^3. The problems created by this huge depletion of aquifers result from the declining water tables, and from the degradation of water quality by pollution loads or saline intrusion in coastal aquifers. One important health problem is the arsenic pollution detected in Bangladesh, which is poisoning the impoverished population. The poorest farmers are the first group threatened by this massive depletion of resources, because they have limited access to infrastructures such as electricity and food distribution facilities, and to farm inputs, production technologies and capital financing.

The Ogallala aquifer in the North America high plains covers 450,000 km^2 and supplies water to irrigate 5 Mha. Withdrawals for irrigation are 26 km^3/yr which include an overdraft of around 10 km^3. The current storage amounts to 3,610 km^3 and the accumulated depletion is estimated at 310 km^3, with a water table decline that could be up to 30 meters (McGuire, 2007). The main worries at present among stakeholders and public administrations are the increase of pumping costs, the effects on dwindling surface flows, and the impact on near-stream habitats. The only measure taken so far by federal, state and local public agencies is the monitoring of water level changes, started in the 1990s. But no control measures to stabilize of reduce overdraft have been taken yet.

Groundwater depletion in the Indus-Ganges basins and the Ogallala aquifer, together with groundwater depletion in Southwestern USA, Australia, Spain and Mexico, demonstrate that aquifer mismanagement is the rule, and that sustainable management of groundwater is a complex task very difficult to achieve. The reason behind the pervasive aquifer mismanagement worldwide is that groundwater is a common pool resource with environmental externalities, and adequate management can only be brought about by cooperation of stakeholders through the right institutional setting.

The absence of regulation has been supported by the arguments put forward by Gisser & Sanchez (1980), and by the ensuing literature on groundwater management (Koundouri, 2004). The so-called *Gisser-Sanchez effect* claims that welfare gains from policy interventions are negligible in aquifer management, when comparing with non regulation or *free-market* outcomes. An essential element for the validity of this approach is the disregard for aquatic ecosystems linked and dependent on large aquifers. When environmental externalities from overdraft are taken into account, this approach becomes untenable (Esteban, 2010). The policy issue is important, because of the mentioned severe groundwater depletion problems in the Indus and Ganges basins, the Northern China plain, the North America high plains and other regions, causing large scale degradation of aquatic ecosystems. This *laissez faire* approach deserves revision, in order to demonstrate that policies and social interventions for sustainable aquifer management not only make sense but are also very much needed.

There are only very few real world cases of aquifers attempting good management through collective action. To the best of our knowledge, this collective action has been achieved in only two small aquifers in Santa Clara (California, USA) and Vall d'Uxo (Spain), and only in one large aquifer in Eastern La Mancha (Spain). The common feature in the three cases has been the organization by stakeholders of extractions control, but with distinctive features in each case: huge imports of water in Santa Clara, changes in irrigation technologies in Vall d'Uxo, and social agreement to reduce extractions and become rightful users in Eastern La Mancha. These cases are important lessons on how to design incentives for the management of water quantity and quality.

2 WATER QUALITY AND NONPOINT POLLUTION

Water quality is an essential condition for having living rivers with healthy aquatic ecosystems. At present, the pressure on water resources is growing rapidly both in terms of expanding water extractions and quality degradation from pollution loads. Water quality degradation is pervasive in most water courses around the world, driven by the escalating pollution loads from anthropogenic point and nonpoint sources.

In high income countries, there have been large investments in sewage networks and water treatment facilities during recent decades to control point pollution, which have stabilized or in some cases reduced the concentration of pollutants in rivers. Nonpoint pollution is much more difficult to tackle, because control measures are very difficult to design, implement and enforce. As a consequence of the abatement of point pollution, the relative importance of nonpoint pollution loads is increasing in high income countries. In medium and low income countries, rivers and aquatic ecosystems are being degraded by the surge in point pollution loads from urban and industrial sources, and large tracts of water courses become unsuitable for many water uses.

Policies to control nonpoint pollution are not so easy to design, and some authors such as Vitousek *et al*. (2009) mention the USA and the EU as examples of reductions in nutrient imbalances, in spite that pollution remains very high in their water media. In Europe, results appear disappointing after the considerable efforts to curb pollution. European regulations include the Urban Wastewater Directive (with investments above 100,000 million €), the Nitrates Directive, both of 1991, and the Water Framework Directive of 2000.

The huge investments of the Wastewater Directive should have reduced urban pollution, but the European data (EEA, 2009) for the last 15 years on nitrate concentration indicate a slight reduction in rivers and a 50% increase in aquifers. The data from OECD (2008) confirm this poor quality improvement, with most major European rivers showing no abatement of nutrients or even a worsening in some rivers (Table 1). These data show this poor behavior which hampers the recovery of water quality in the last thirty years. The Biochemical Oxygen Demand (BOD) has improved in most European countries except in Belgium (Escaut), UK (Thames) and Netherlands (Maas) which show no improvement. The improvement in BOD took place in Germany and Denmark in the beginning of the 1990s, and in France, Spain and Italy in the beginning of the 2000s.

The worst water quality results are for nitrates, with most countries showing no improvement in the last thirty years, and some rivers such as the Loire, Guadalquivir and Strimonas even increasing nitrate loads in the beginning of the 2000s. The only countries that reduce nitrate loads are Germany (Rhein, Elbe, Wesser) and Norway (Skienselva) during the late 1990s. Phosphorus pollution loads show no improvement in the majority of rivers, with pollution reductions taking place at end of the 1990s in the Rhein, Elbe and Wesser (Germany), Thames (UK), Gudena (Denmark), Maas (Netherlands) and Ebro (Spain).

The Nitrates Directive was based on voluntary compliance, and recently farmers have been required to keep a nitrogen balance book, with uncomplying farmers drawn by chance being penalized in their agricultural subsidies. The Nitrates Directive only applies to cultivation over aquifers declared officially polluted, but not to cultivation over whole basins or very polluting

Table 1. Water quality in selected European rivers (average 2002–2004).

Country	Watershed	BOD (mg O_2/L)	Nitrates (mg N/L)	Phosphorus (mg P/L)	Lead (μg/L)	Cadmium (μg/L)	Chromium (μg/L)	Copper (μg/L)
Norway	Skienselva	2.0*	0.2	0.01	0.2	0.02	0.11	0.62
Sweden	Dalalven		0.1	0.02	0.5*	0.02	0.37*	1.48
Denmark	Gudena	1.9	1.3	0.09				
UK	Thames	3.4	6.6	0.66	2.9	0.10	1.17	6.63*
Netherlands	Maas	2.5	3.6	0.21	2.8	0.15	1.77	3.77
Belgium	Escaut	3.6	4.7	0.66	12.0	0.67	9.93	10.10
Germany	Rhein	3.0	2.5	0.14	3.0	0.20	2.55	6.22
	Elbe	6.9	3.0	0.17	2.2	0.18	1.20	4.36
	Weser	2.8	3.7	0.14	4.5*	0.20	2.03*	3.56
France	Loire	3.2	3.1	0.21		0.40*		
	Seine	3.1*	5.6	0.63*	22.1*	2.18*	24.67*	15.03*
Spain	Guadalquivir	4.2*	6.1*	0.95*	10.2*	1.87*		5.73*
	Ebro	1.9	2.2	0.09	7.5	0.23*	0.92*	1.61*
	Guadiana	1.6	1.8	0.69*		3.39		
Portugal	Tejo	2.3	1.0	0.20	11.0	3.00	22.33*	2.10
Italy	Po	1.3	2.5	0.25				
Greece	Strimonas		1.8	0.14		0.64*		
Turkey	Porsuk	1.4	1.5	0.06	12.2	6.50	7.50	5.67

The symbol * indicates that the average is for years 1999–2001 or before. The Biochemical Oxygen Demand (BOD) measures pollution by organic matter, and water is considered drinkable for BOD between 0.75 y 1.50 mg O_2/L.
Source: OECD (2008).

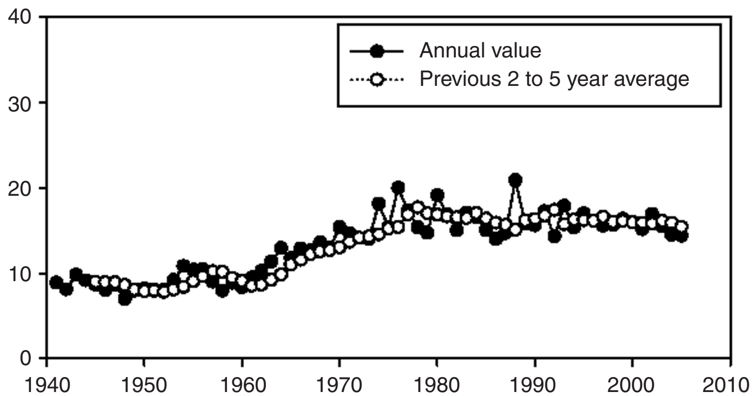

Figure 1. Net nitrogen inputs for the Mississippi Basin (kg N/ha/yr).
Source: EPA (2007).

crops not receiving subsidies (e.g. greenhouses). Water pricing advanced by the Water Framework Directive as the key policy measure does not seem either a good instrument to curb nitrate pollution, since the pollution driver is fertilizer not water.

In the USA, it seems that there is no improvement in nonpoint pollution loads over the last decade. The large study completed by NOAA (National Oceanic and Atmospheric Administration) in 2000 on hypoxia in the Northern Gulf of Mexico, has not spurred any significant reduction of nitrogen loads in the Mississippi basin as Figure 1 indicates (EPA, 2007). The major effort in the USA to curb nonpoint pollution has been made in the Chesapeake Bay, but results there show only moderate reductions. From 1985 to 2007, the nitrogen loads have fallen from 153,000 t to 119,000 t [t = tonne = 1,000 kg] and the phosphorus loads from 12,300 to 8,300 t, which are still far from the sought thresholds of 79,000 t of nitrogen and 5,800 t of phosphorus. The implication is that the current voluntary measures have to be supplemented with more strong regulatory measures (Linker *et al*., 2009).

3 CONCLUSIONS

The achievements of developed countries to control nonpoint pollution are quite modest, and the nonpoint pollution policies of the USA and Europe are not good enough examples to inspire policies in developing countries (Albiac, 2009). A case in point is Chinese water policies that must deal with serious water scarcity problems in both the Yellow River and the Yangtze River basins, and also with severe water quality degradation problems in many tracts of rivers around the country. Chinese policy makers are worrying about nonpoint pollution from agriculture, when in fact they should worry first on urban and industrial point pollution. Ongley & Tao (2009) indicate that appropriate water policies in China require undertaking good studies and assessments on pollution loads from all sources in the whole country.

Regulation in both USA and EU has contributed to the abatement of point source pollution from urban and industrial sources, due to the construction of treatment facilities, and the decline in some emissions of dangerous substances from industrial processes. But the improvement of water quality in USA and European rivers is far from obvious for the majority of basins and pollutants, despite all legislation and investments.

There has been a certain improvement of some quality parameters in several surface and coastal water bodies, with the resulting reduction in pressure on their aquatic ecosystems. However, no substantial improvements are detected in the water quality of USA and EU rivers and aquifers. The problems of agricultural nonpoint source pollution remain, in particular those of nutrients and pesticides, and also the problems of water scarcity in arid and semiarid regions of the USA and European countries (Albiac *et al*., 2009). One of the factors explaining these difficulties is that nonpoint pollution is a *common pool resource* (or public bad) where economic instruments such as taxes and subsidies fail.

The current policy practice in the protection of natural resources consists on actions to compensate private benefits of local agents causing damages through market instruments (Hardner & Rice, 2002; Pagiola *et al*., 2004), or to promote conservation with large mitigation investments by governments, international agencies and private foundations in protected natural reserves (Pimm *et al*., 2001; Balmford *et al*., 2002).

However, these policy practices are unable to curtail the massive degradation of natural resources and ecosystems worldwide. What seems to be needed is the cooperation of the stakeholders managing and using the resources. Therefore, the policy effort has to be focused on nurturing cooperation. The economic argument supporting this collective action approach is that natural resources are mostly common pool resources, requiring cooperation rather than just economic instruments that are likely to fail with public goods. The recent collapse of climate change negotiations illustrates the consequences of cooperation failure among countries and stakeholders.

The key policy question in nonpoint pollution is that an appropriate institutional setting is required to induce farmers' cooperation, because pollution abatement is impossible without farmers' involvement and active support in order to spur the needed collective action.

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