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Application of a groundwater quality index as an assessment and communication tool in agro-environmental policies — Two Portuguese case studies

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Summary A simple methodology based on multivariate analysis is developed to create a groundwater quality index (GWQI) and a composition index (GWCI), with the aim of monitoring the joint influence of agriculture on several key parameters of groundwater chemistry and potability. The methodology is based on the definition of two standard water samples of high and low quality that, together with the actual data, are run through a statistical algorithm known as correspondence factor analysis. The applicability of the constructed indices as an assessment and communication tool is evaluated in two case studies in the south of Portugal. Index maps are created, providing a comprehensive picture of the contamination problem and easily interpretable for people outside the scientific domain. Such maps could be particularly useful in agro-environmental policies such as Nitrates Directive 91/676/EEC. Drawn up in order to reduce the environmental load of nutrients from agriculture, its implementation continues to be very problematic in most EU member states. In the case studies, the GWQI maps reveal that groundwater quality in the upper aquifers is extremely low, with an almost complete absence of potable water. However, the impact of agricultural activity on the groundwater composition shows a large spatial variability, which is accurately depicted by the GWCI maps and mainly related to crop type and aquifer lithology. In addition, contamination-freshening sequences occur and are displaced by groundwater flow, partly affected by faults that form either preferential flow paths or flow barriers.

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Introduction

Since the beginning of the nineties serious efforts have been made to combat surface and groundwater contamination by agricultural practices across the European Union (EU), through the implementation of national and international policies. Despite such efforts, nitrate pollution was considered by the European Environment Agency (EEA, 2003) as an area of no progress. For instance, in the period of 1996–1998 about 40% of all the EU groundwater monitoring stations registered nitrate concentrations above 25 mg NO_3^-/l, whereas 20% exceeded the drinking water guideline of 50 mg/l (EC, 2002).

Council Directive 91/676/EEC was drawn up with the specific purpose to protect waters against pollution caused by nitrates from agricultural sources, therefore typically labelled the Nitrates Directive. Curiously, the vast majority of the EU members have found it extremely difficult to meet its objectives, as its transposition into National law and the application of the measures have suffered severe delays (CEC, 1997; CEC, 1998; Goodchild, 1998; EC, 2002). In fact, the Committee on Agriculture and Rural Development of the European Parliament (EP, 2000) stated that the Nitrates Directive was one of the most striking examples of inadequate and slow incorporation of Community law into National law, as is illustrated in Table 1. According to Goodchild (1998), the designation of nitrate vulnerable zones (NVZs) and the application of action programmes are strongly hindered by the agricultural lobby, as it fears that the production and consequently the financial situation of many farmers will be seriously affected. As Ondersteijn et al. (2002) put it, producing less than technically possible in order to protect the environment is a relatively new thought in agriculture. The lack of co-operation between ministries of agriculture and environment is frequently an obstacle on the way to a swift implementation. Disagreements are worsened by the complex nature of the nitrogen cycle and the various human activities that affect it.

In Portugal, the intensification of agriculture occurred at the beginning of the eighties and lead to an increased and often uncontrolled use of mineral fertilisers, often encouraged by EU subsidies. Currently, nitrate pollution of groundwater has reached concerning levels, especially in the shallow aquifers. Analyses of more than 300 groundwater extraction wells between 1996 and 2000 in the Ribatejo e Oeste and Beira Litoral coastal provinces, shown in Fig. 1, revealed that 43% had concentrations above 25 mg/l and 32% exceeded the drinking water guideline value (Batista et al., 2004). In the Lisbon district, these percentages corresponded to 26% and 15%, respectively, of a total of 550

Table 1 Implementation of Nitrates Directive by EU member states

	Transposition of Nitrates Directive into National law	Designation of NVZs[a]	Establishment of code of good agricultural practice	Establishment of action programmes	Completion of review of NVZ designations		NVZ area designated	NVZ area assessed by EC[b]
					1st	2nd		
Stipulated completion date	20/12/1993[c]	20/12/1993[c]	20/12/1993[c]	20/12/95	21/12/97	21/12/01	(% of total area)	
Austria	× (1995)	× (1996[d])	× (1996)	× (1996)	✓	✓	100	–
Belgium	× (1998)	× (1999)	× (1997)	× (1999)	× (2002)	×	9	69
Denmark	✓	✓[d]	✓	× (1996)	✓	✓	100	–
Finland	× (1995)	× (2000[d])	× (1995)	× (2000)	✓	✓	100	–
France	✓	✓	✓	× (1996)	×	×	48	55
Germany	× (1996)	× (1994[d])	× (1996)	× (1996)	✓	✓	100	–
Greece	× (1997)	× (1999)	× (1994)	× (2000)	× (2001)	×	11	18
Ireland	× (1995)	× (1995[e])	× (1996)	× (2003)	× (2003[d])	✓	0	9
Italy	× (1999)	× (1999)	✓	× (1998)	×	×	2	31
Luxembourg	× (1994)	× (1994[d])	× (1996)	✓	✓	✓	100	–
Portugal	× (1997)	× (1997)	× (1997)	× (1998)	× (2003)	×	0.2	14
Spain	× (1996)	× (1998)	× (1998)	× (1999)	×	×	6	20
Sweden	× (1996)	× (1996)	× (1996)	✓	×	×	9	19
the Netherlands	× (1994)	× (1994[d])	× (1994)	× (1997)	✓	✓	100	–
United Kingdom	× (1996)	× (1996)	✓[f] (1998)	× (1998)	×	×	3	11

Shaded areas indicate infringement procedure started by the EC against Member State by the end of 2001.

[a] Nitrate vulnerable zone.

[b] Period 1999–2000.

[c] 01-Jan-95 for Austria, Finland and Sweden.

[d] Whole territory designated as NVZ.

[e] No NVZs designated.

[f] Already had a code and tailored it to the Nitrates Directive; sources: CEC (1997), CEC (1998), EP (2000), EC (2002).